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REPORT No. 664

WIND-TUNNEL INVESTIGATION OF AN N. A. C. A. 23012 AIRFOIL WITH VARIOUS ARRANGEMENTS OF SLOTTED FLAPS

By CARL J. WENZINGER and THOMAS A. HARRIS

1939

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AERONAUTIC SYMBOLS

1. FUNDAMENTAL AND DERIVED UNITS

	Symbol	Metric		English	
		Unit	Abbreviation	Unit	Abbreviation
Length	l	meter	m	foot (or mile)	ft. (or mi.)
Time	t	second	s	second (or hour)	sec. (or hr.)
Force	F	weight of 1 kilogram	kg	weight of 1 pound	lb.
Power	P	horsepower (metric)		horsepower	hp.
Speed	V	kilometers per hour	k.p.h.	miles per hour	m.p.h.
		meters per second	m.p.s.	feet per second	f.p.s.

2. GENERAL SYMBOLS

W, Weight $= mg$

g, Standard acceleration of gravity $= 9.80665$ m/s^2 or 32.1740 ft./sec.^{2}

m, Mass $= \frac{W}{g}$

I, Moment of inertia $= mk^2$. (Indicate axis of radius of gyration k by proper subscript.)

μ, Coefficient of viscosity

ν, Kinematic viscosity

ρ, Density (mass per unit volume)

Standard density of dry air, 0.12497 kg-m^{-4}-s^2 at 15° C. and 760 mm; or 0.002378 lb.-ft.$^{-4}$ sec.^{2}

Specific weight of "standard" air, 1.2255 kg/m^3 or 0.07651 lb./cu. ft.

3. AERODYNAMIC SYMBOLS

S, Area

S_w, Area of wing

G, Gap

b, Span

c, Chord

$\frac{b^2}{S}$, Aspect ratio

V, True air speed

q, Dynamic pressure $= \frac{1}{2}\rho V^2$

L, Lift, absolute coefficient $C_L = \frac{L}{qS}$

D, Drag, absolute coefficient $C_D = \frac{D}{qS}$

D_0, Profile drag, absolute coefficient $C_{D_0} = \frac{D_0}{qS}$

D_i, Induced drag, absolute coefficient $C_{D_i} = \frac{D_i}{qS}$

D_p, Parasite drag, absolute coefficient $C_{D_p} = \frac{D_p}{qS}$

C, Cross-wind force, absolute coefficient $C_C = \frac{C}{qS}$

R, Resultant force

i_w, Angle of setting of wings (relative to thrust line)

i_t, Angle of stabilizer setting (relative to thrust line)

Q, Resultant moment

Ω, Resultant angular velocity

$\rho\frac{Vl}{\mu}$, Reynolds Number, where l is a linear dimension (e.g., for a model airfoil 3 in. chord, 100 m.p.h. normal pressure at 15° C., the corresponding number is 234,000; or for a model of 10 cm chord, 40 m.p.s., the corresponding number is 274,000)

C_p, Center-of-pressure coefficient (ratio of distance of c.p. from leading edge to chord length)

α, Angle of attack

ϵ, Angle of downwash

α_0, Angle of attack, infinite aspect ratio

α_i, Angle of attack, induced

α_a, Angle of attack, absolute (measured from zero-lift position)

γ, Flight-path angle

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WIND-TUNNEL INVESTIGATION OF AN N. A. C. A. 23012 AIRFOIL WITH VARIOUS ARRANGEMENTS OF SLOTTED FLAPS

By Carl J. Wenzinger and Thomas A. Harris

SUMMARY

An investigation was made in the 7- by 10-foot wind tunnel and in the variable-density wind tunnel of the N. A. C. A. 23012 airfoil with various slotted-flap arrangements. The purpose of the investigation in the 7- by 10-foot wind tunnel was to determine the airfoil section aerodynamic characteristics as affected by flap shape, slot shape, and flap location. The flap position for maximum lift; polars for arrangements considered favorable for take-off and climb; and complete lift, drag, and pitching-moment characteristics for selected optimum arrangements were determined. The best arrangement was tested in the variable-density tunnel at an effective Reynolds Number of 8,000,000. In addition, data from both wind tunnels are included for plain, split, external-airfoil, and Fowler flaps for purposes of comparison.

The optimum arrangement of the slotted flap was superior to the plain, the split, and the external-airfoil types of flap on the basis of maximum lift coefficient, low drag at moderate and high lift coefficients, and high drag at high lift coefficients. The increment of maximum lift due to the slotted flap was found to be practically independent of the Reynolds Number over the range investigated. The slotted flap, however, gave slightly lower maximum lift coefficients than the Fowler flap. It was found that slot openings in the airfoil surface at the flap caused a measurable increase in drag of the airfoil for the condition of high-speed flight even if the slot was smoothly sealed on the upper surface and there was no flow through the slot. It was also found that, in order to obtain the highest lift coefficients, the nose of the flap should be located slightly ahead of and below a slot lip that directs the air downward over the flap. The nose of the flap should have a good aerodynamic form and the slot entry should have an easy shape to obtain low drags at moderate lift coefficients.

INTRODUCTION

Most present-day airplanes, because of their high wing loadings and cleanness of aerodynamic design, employ some form of lift-increasing and drag-increasing device to assist in landing them in a field of restricted size. Also, increases in lift without increases in drag appear desirable in the take-off and in the climbing conditions of flight.

The foregoing considerations indicate that the most desirable form of high-lift device is one capable of providing high lift with relatively low drag, and also probably high lift with high drag. Some other desirable aerodynamic features are: no increase in drag with the flap neutral; small changes in wing pitching moment with flap deflection; low forces required to operate the flap; and freedom from possible hazard due to icing.

Some form of slotted flap was believed to be the most promising for the conditions noted. Various forms of slotted flap include the external-airfoil (references 1 and 2), the Fowler (references 3 and 4), and the Handley Page types (references 5, 6, 7, 8, and 9).

The present investigation was made in two main parts. The tests reported in part I were made in the 7- by 10-foot tunnel of slotted flaps somewhat similar to the Handley Page type. Flaps of three different sections and with several different slot shapes were tested. Surveys were made of flap location to obtain the best aerodynamic characteristics for each arrangement. In addition, a plain flap, a split flap, an external-airfoil flap, and a Fowler flap were included for purposes of comparison.

Part II reports tests made in the variable-density tunnel of the best slotted flap arrangement (2–h) developed in part I, to determine the effects at high Reynolds Numbers. In addition, slotted flap 2–h was tested in combination with a 60-percent-chord plain flap to see whether, as in previous unpublished tests of the plain flap alone, rounded lift-curve peaks could be obtained.

The tests reported in part II were made by the variable-density-tunnel staff and the material presented as part II was prepared for publication by Harry Greenberg and Neal Tetervin.

I. TESTS IN 7- BY 10-FOOT WIND TUNNEL

APPARATUS AND TESTS

THE MODIFIED 7- BY 10-FOOT WIND TUNNEL

Before the present investigation was started, the 7- by 10-foot open-jet wind tunnel (reference 10) had been modified, mainly by the addition of a closed test section and a new entrance cone: (See fig. 1.) With these changes, the static pressure is practically constant along the axis of the test section and the noise during tunnel operation is fairly low. In addition, by making the top and the bottom of the test section parallel, an arrangement is obtained whereby two-dimensional-flow tests can conveniently be made of large-chord models completely spanning the jet in a vertical plane. The use of such an installation permits a large ratio of chord of model to height of jet together with small wind-tunnel corrections (references 11 and 12) so that the range of Reynolds Numbers of the tests for obtaining airfoil section data in a given wind tunnel can be considerably increased.

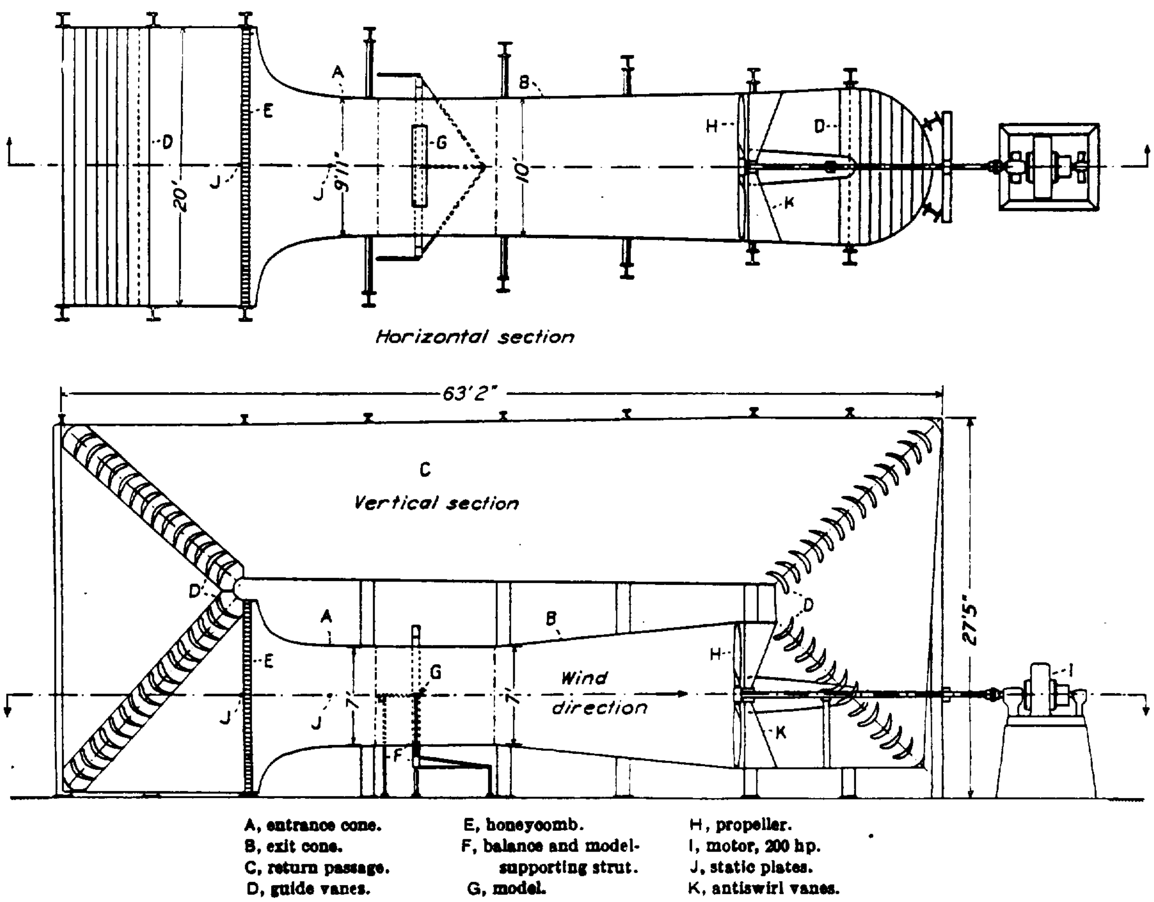

FIGURE 1.—Diagram of the 7- by 10-foot wind tunnel with closed test section.

The wind-tunnel balance has been slightly modified by installing tubular supports on the top and the bottom of the balance frame surrounding the test section so that the model can be held vertical. The tubular supports extend through circular holes in the closed test section to sockets with clamps in the ends of the model; they can be rotated with a motor drive by gears and shafting to change the angle of attack from outside the wind tunnel. A clearance of about 1/32 inch is allowed between the ends of the model and the top and the bottom of the test section (fig. 2). Any contact between the model and the tunnel walls is indicated by the flashing of neon lamps connected in an electrical circuit including the walls of the test section and thin metal plates fastened to each end of the model.

The standard force-test tripod used with the previous open-jet wind tunnel (reference 10) to support horizontally the smaller finite-aspect-ratio models has been replaced by a single cantilever streamline strut. The opening in the floor of the closed test section through which the strut passes is made airtight by a mercury seal. The existing scales are used with both types of test; however, in the case of the two-dimensional-flow tests, lift is measured on the cross-wind scale and pitching moment on the yawing-moment scale. (See reference 10 for arrangement of scales.)

Sphere tests have been made to obtain an indication of the turbulence present in the air stream of the closed test section. The turbulence was found to have changed slightly from that of the open-jet wind tunnel, so that the turbulence factor (reference 13) has been increased from a value of 1.4 to 1.6. The dynamic pressure of the air stream at the working section in either horizontal or vertical planes is constant within ±0.5 percent, and the air stream is parallel to the axes of the test section within ±0.5°.

MODELS

Plain airfoil.—The basic model, or plain airfoil, (fig. 3) was built of laminated pine to the N. A. C. A. 23012 section (table I) and has a chord of 3 feet and a span of 7 feet. The trailing-edge portion of this airfoil was made easily removable so that the model can be quickly altered for testing different flap arrangements.

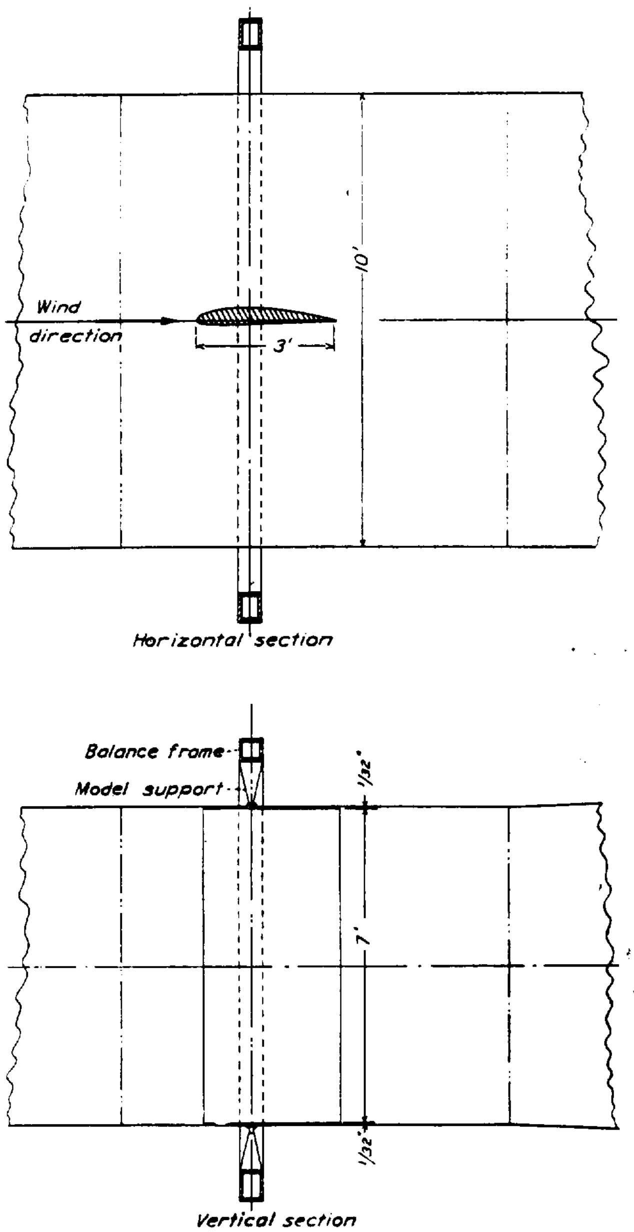

FIGURE 2.—Model installation for two-dimensional-flow tests in the 7- by 10-foot wind tunnel.

Split flap.—A simple split flap with a chord 20 percent of the airfoil chord (fig. 3) was used in conjunction with the plain airfoil. This flap is of plywood, 1/4 inch thick, and is fastened to the model by screws. The flap angles (0° to 75°) are set by wooden blocks cut to the desired angles and placed between the flap and the airfoil.

Plain flap.—The plain flap (fig. 3) also has a chord 20 percent of the airfoil chord and is mounted on a removable section, which replaces that of the plain airfoil. Fittings supporting the wooden flap are of thin steel and are equipped with ball-bearing hinges so that the hinge moments of the flap can be measured. The flap angles (38° up to 75° down) are set by a push rod and bell cranks, so arranged that the settings can be changed from outside the wind tunnel. The gap between the flap and the airfoil is sealed top and bottom by thin metal plates.

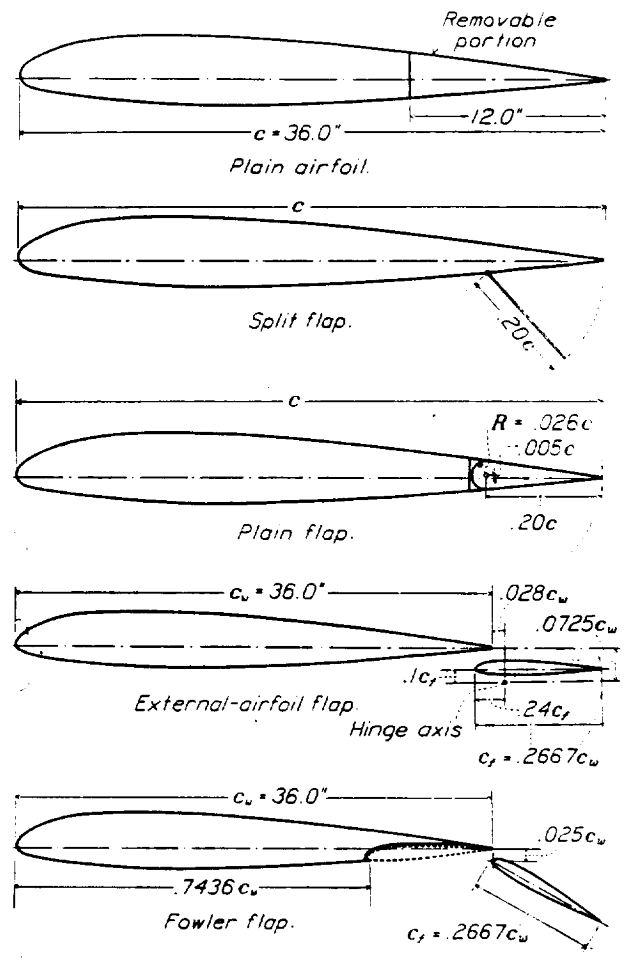

FIGURE 3.—Sections of the plain N. A. C. A. 23012 airfoil and of the airfoil with different types of flap.

External-airfoil flap.—The external-airfoil flap, available from another investigation, was used without alteration although it was somewhat larger than desired, having a chord 26.67 percent of the airfoil chord (fig. 3). The flap has the N. A. C. A. 23012 section and was located with respect to the main airfoil in accordance with the results of reference 2. The flap is supported on the main airfoil by thin metal fittings arranged so that the flap angle can be set 3° up to 50° down.

Fowler flap.—The external-airfoil flap was also used as a Fowler flap (26.67 percent of the main airfoil chord) after modification of the main airfoil (fig. 3). No actual data were available showing the best location of a Fowler flap of N. A. C. A. 23012 profile with a main airfoil of the same profile; however, the flap was located on the basis of tests of external-airfoil flaps of N. A. C. A. 23012 profile (reference 2) and of tests of Fowler flaps of Clark Y profile (reference 4). The flap is supported on the main airfoil by thin metal fittings so that the flap can be set from 0° to 60° down when completely extended. The main airfoil is arranged so that the N. A. C. A. 23012 Fowler flap may be almost completely retracted for the flap-neutral condition. (See fig. 3.)

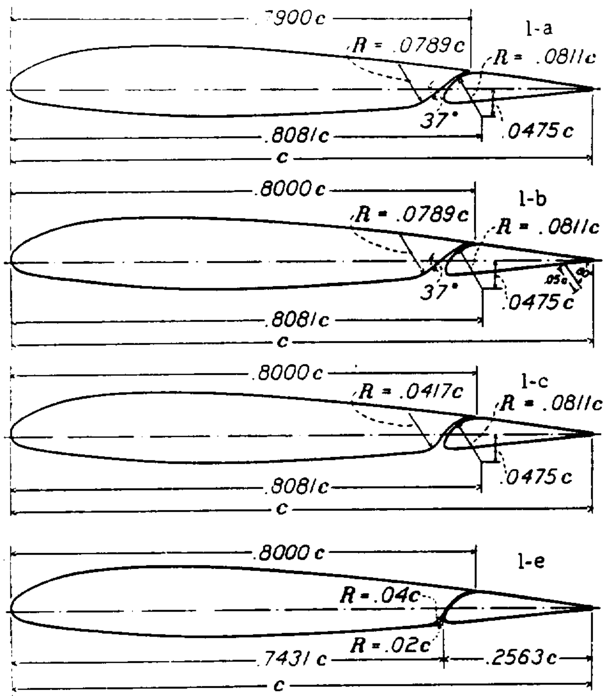

FIGURE 4.—Sections of airfoil with arrangements of slotted flap 1.

Slotted flap 1.—The three slotted flaps tested are designated by numbers and the slot shapes by appended letters. Slotted flap 1 (fig. 4), which is representative of recent Handley Page practice, was built according to dimensions taken from reference 8. The ordinates for this flap are given in table II. The slot variations used with flap 1 are shown in figure 4 and in table I. Shape a is also representative of recent Handley Page practice and was built according to dimensions taken from reference 8. Shape b is the same as shape a except for an increase in the length of the slot lip to close the slot on the upper surface of the airfoil with the flap neutral. Shape c is an intermediate step toward closing the slot on the lower surface, and shape e has the slot sealed all the way through the airfoil when the flap is neutral. Shape e was further modified by different roundings of the slot entry. The slot entry with the 0.02c radius is designated as e_2 and the one with the 0.04c radius, as e_4.

Two methods of hinging flap 1 were employed. The first method was to hinge it about a single predetermined axis location obtained from reference 8 for comparison with recent Handley Page practice. The second method was to mount the flap on the main airfoil by special fittings that allowed the flap to be located at any point over a considerable area with respect to the main airfoil.

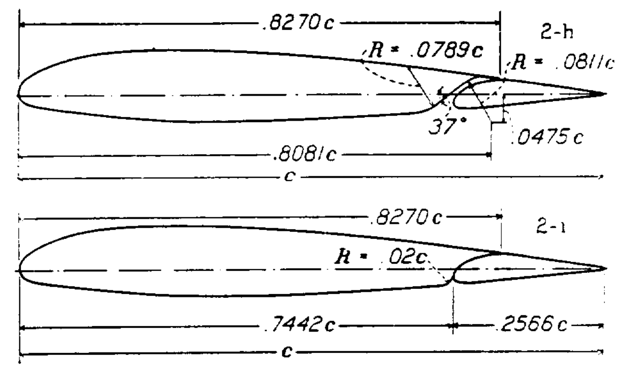

FIGURE 5.—Sections of airfoil with arrangements of slotted flap 2.

Slotted flap 2.—It was believed that a good airfoil section would probably make the best flap shape, especially from considerations of drag at low flap deflections. The front portion of slotted flap 2 was therefore made to the N. A. C. A. 6318 airfoil section back to the maximum thickness and was faired into the contour of the main airfoil over the rest of its length. The arrangements of slotted flap 2 and the slot variations used in conjunction with it are shown in figure 5 and in tables I and II. Slot shape h is the same as shape a except that the lip is made long enough to seal the slot on the upper surface of the airfoil with the flap neutral. Slot shape i (table I) is sealed all the way through the wing with the flap neutral except for the radius at the slot entry. Flap 2 was hinged in a manner similar to the second method for flap 1.

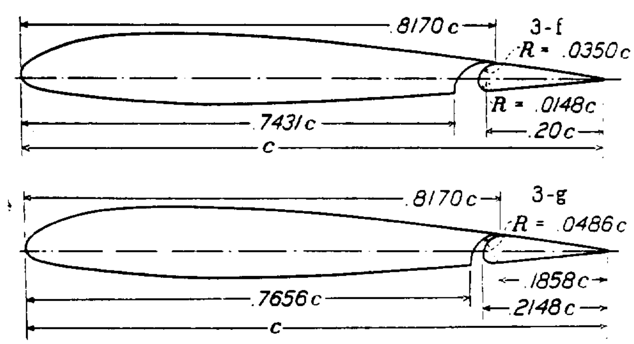

FIGURE 6.—Sections of airfoil with arrangements of slotted flap 3.

Slotted flap 3.—Slotted flap 3 has an arbitrary shape with a very blunt nose (fig. 6). Slot shape f is the same as slot shape e except for the longer lip to seal the slot on the upper surfaces of the airfoil when the flap is neutral. The ordinates for this slot shape are given in table I. Slot shape g (fig. 6) is designed to give a good expanding slot shape for flap deflections up to 50° with the flap hinged at a point on the lower surface of the flap 20 percent of the airfoil chord from the trailing edge. The same main fittings were used on the airfoil to support this flap as for flaps 1 and 2; they allow the flap to be located at any point over a considerable area with respect to the main airfoil.

GENERAL TEST CONDITIONS

The two-dimensional-flow installation in the 7- by 10-foot closed-throat wind tunnel was used for the tests. (See fig. 2.) The regular six-component balance (reference 10) was used to measure the lift, the drag, and the pitching moment of the model. The hinge moments were measured with a special torque-rod balance.

A dynamic pressure of 16.37 pounds per square foot was maintained for all of the tests except those of the external-airfoil and the Fowler flaps. This dynamic pressure corresponds to a velocity of about 80 miles per hour under standard atmospheric conditions and to an average test Reynolds Number of 2,190,000. Because of the turbulence in the tunnel, the effective Reynolds Number R_e of the tests was approximately 3,500,000. The models with the external-airfoil and the Fowler flaps were tested at a dynamic pressure corresponding to a velocity of 63.2 miles per hour under standard atmospheric conditions. With this velocity, the test Reynolds Numbers were also 2,190,000 for the tests with the external-airfoil flap and with the Fowler flap fully extended, based on the sum of the chords of the main wing and the flap. In addition, tests were made of the wing with the Fowler flap fully retracted at both 80 and 63.2 miles per hour.

Tests were first made of the plain airfoil and of the airfoil with split, plain, external-airfoil, and Fowler flaps through a complete range of flap deflections and angles of attack for comparison with other tests and also for comparison with the slotted flaps of the present investigation. As an example of one of the recently used Handley Page slotted flaps (reference 8), a few tests were made of one slotted flap hinged about a predetermined axis location. The greater part of the investigation, however, consisted of surveys to determine the optimum flap positions and deflections for maximum lift and climb. Sufficient angles of attack at each flap deflection were taken to determine envelope polars over the complete lift range from zero to maximum lift. Data were obtained at 2° increments of angle of attack and at 10° increments of flap deflection for each flap location. Lift, drag, and pitching moments were measured for all positions of the flaps over the angle-of-attack range tested. Hinge moments of the plain flap and of one slotted-flap arrangement were also measured.

RESULTS AND DISCUSSION

COEFFICIENTS

All test results are given in standard section nondimensional coefficient form as follows:

c_l, section lift coefficient (l/qc).

c_{d_0}, section profile-drag coefficient (d_0/qc).

$c_{m_{(a.c.)_0}}$, section pitching-moment coefficient about aerodynamic center of section with flap in neutral position $(m_{(a.c.)_0}/qc^2)$.

c_{h_f}, section hinge-moment coefficient of flap (h/qc_f^2).

where

l is section lift.

d_0, section profile drag.

$m_{(a.c.)_0}$, section pitching moment.

h, section hinge moment of flap about a specified axis.

q, dynamic pressure $(\frac{1}{2}\rho V^2)$.

c, airfoil chord including flap; for models with external-airfoil and Fowler flaps, c is the sum of the chords of the main airfoil and the flap (c_w+c_f).

c_f, flap chord.

and

α_0 is the angle of attack for infinite aspect ratio.

δ_f, flap deflection.

PRECISION

Accuracy of tests.—From repeat tests the accidental experimental errors in the results presented in this report are believed to lie within the limits indicated in the following table:

α_0	±0.5°	$c_{d_{0\,(c_l=1.0)}}$	±0.0006
$c_{l_{max}}$	±0.03	$c_{d_{0\,(c_l=2.5)}}$	±0.002
$c_{m_{(a.c.)_0}}$	±0.003	δ_f	±0.2°
$c_{d_{0\,(c_l=0)}}$	±0.0003	Flap position	±0.001c

The profile-drag coefficient c_{d_0} of the airfoil-flap combinations has not been corrected for the effect of the flap-hinge fittings. From tests of the airfoil with various flaps neutral and hinge fittings in place, but with all openings in the airfoil surface sealed, it was found that the drag increment was consistently about 0.001. No tests were made to determine the hinge-fitting drag with the flaps deflected because of the large number of additional tests required. The relative merits of the various flap arrangements should not be appreciably affected by hinge-fitting drag since the same hinge fittings were used for all

With a few of the slotted-flap arrangements, two sets of data could be obtained, an indication of two types of air flow. For these cases, the data for the more stable of the two flow conditions were used.

Wind-tunnel corrections.—Certain theoretical corrections have been derived for the effect of tunnel walls on the lift of a flat plate completely spanning the jet at an angle of attack (references 11 and 12). An attempt was made to check these corrections experimentally for an airfoil in the two-dimensional-flow installation and, at the same time, to examine the effect of tunnel walls on the drag and the pitching moment. This experimental investigation showed the correction for lift to be about 1 percent greater than the theoretically derived correction for ratios of model chord to jet height up to 0.4. The experimentally determined correction has been used to correct all the lift data presented in this report. The maximum lift coefficients

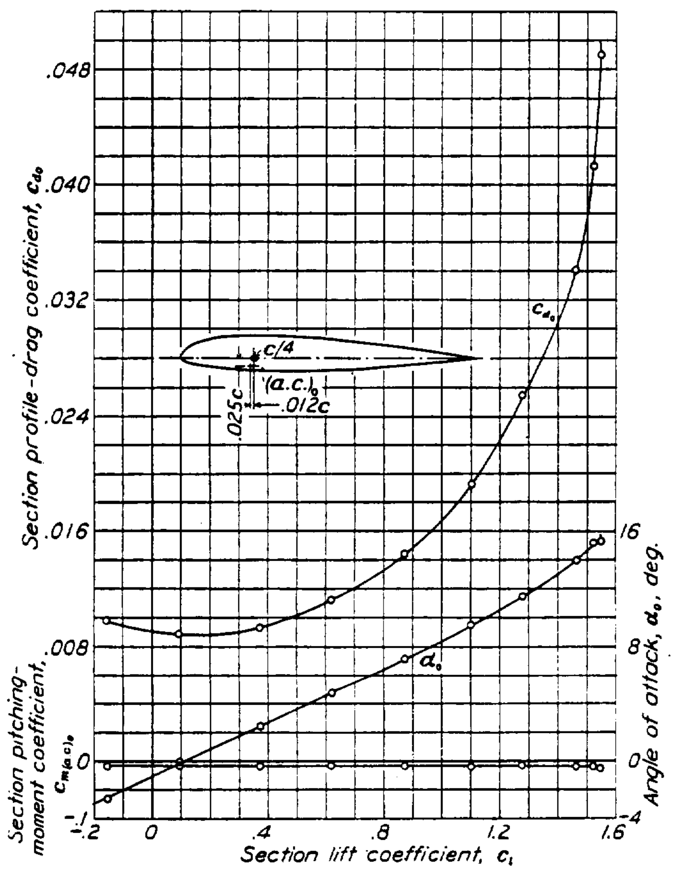

FIGURE 7.—Section aerodynamic characteristics of N. A. C. A. 23012 plain airfoil.

given are about 10 percent higher than those given by a rectangular airfoil of aspect ratio 7 but are probably the same as would be obtained with an airfoil designed to give elliptical lift distribution. This excess of lift was checked by testing the same model (12 inches chord by 84 inches span) in the two-dimensional-flow installation and on the regular three-dimensional-flow set-up. The results agree very closely with the results of pressure-distribution tests and with theoretical considerations of the span loading on rectangular wings. (See reference 14.)

The investigation to determine a correction for drag has not been conclusive. The tests completed up to the present time, however, indicate that the drag results are about 10 percent higher than expected. There are no theoretical corrections for the drag (reference 11) except for a symmetrical body at zero lift. No corrections for the apparent tunnel effect were applied to the drag data. Since any correction would presumably be about the same for any of the airfoil-flap arrangements at given lift coefficients, the relative merits of the various combinations should not be markedly affected by a drag correction. All the drag data have been corrected in accordance with reference 14 by a constant Δc_{d_0} of -0.0008 so as to apply at an effective Reynolds Number of 3,500,000.

Tests to determine tunnel corrections showed that the pitching-moment coefficients required no correction within the experimental accuracy of the tests.

PLAIN N. A. C. A. 23012 AIRFOIL

The section aerodynamic characteristics of the plain N. A. C. A. 23012 airfoil, as determined in the two-dimensional-flow installation, are shown in figure 7. The polar is in good agreement with a generalized polar for the N. A. C. A. airfoils given in reference 14. The mimimum profile drag is, however, about 10 percent higher than the minimum profile drag of the same airfoil section for the same effective Reynolds Number. This difference is not considered serious, and some contemplated additional tunnel-effect tests will probably furnish information as to the indicated differences. The pitching-moment coefficient about the aerodynamic center checks the pitching-moment coefficient given in reference 14 for the same effective Reynolds Number. The slope of the lift curve $dc_l/d\alpha$ is 0.107 from the present tests, as compared with 0.098 from the results for infinite aspect ratio of tests of models of finite aspect ratio given in reference 14. This difference in lift-curve slope, although not yet adequately explained, should not affect the relative merits of the test results of the flap combinations presented in this report. The angle of zero lift, within the experimental accuracy of the tests, agrees with the angle of zero lift as determined by other tests (reference 14).

FLAPS FOR COMPARISON WITH SLOTTED ARRANGEMENT

Split flap.—The section aerodynamic characteristics of the N. A. C. A. 23012 airfoil with a 0.20c split flap are shown in figure 8. The lift curves have about the same slope as that of the plain airfoil. The angle of attack for maximum lift decreases from about 15° with the flap neutral to 14° with the flap down 45°. With the flap down 60° or 75°, however, the angle of maximum lift is only about 12°, a change of 3° from the plain airfoil. A change of this magnitude in the angle of attack for maximum lift may have considerable effect on the manner in which a wing stalls for combinations with partial-span split flaps.

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This report is being made available in its present form with the hope it will be of sufficient value to justify its announcement and distribution.

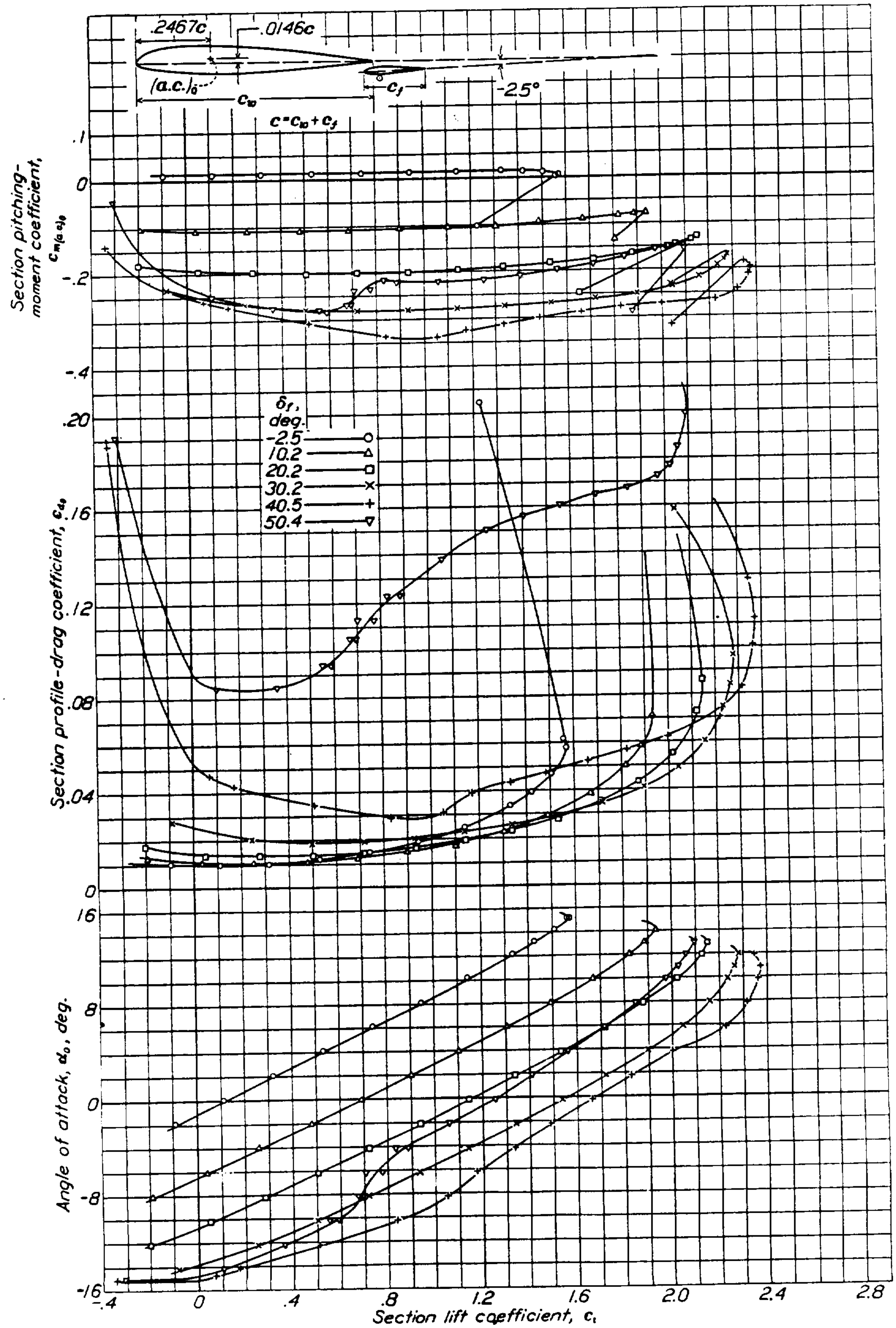

FIGURE 10.—Section aerodynamic characteristics of N. A. C. A. 23012 airfoil with a 0.2667c_w N. A. C. A. 23012 external-airfoil flap.

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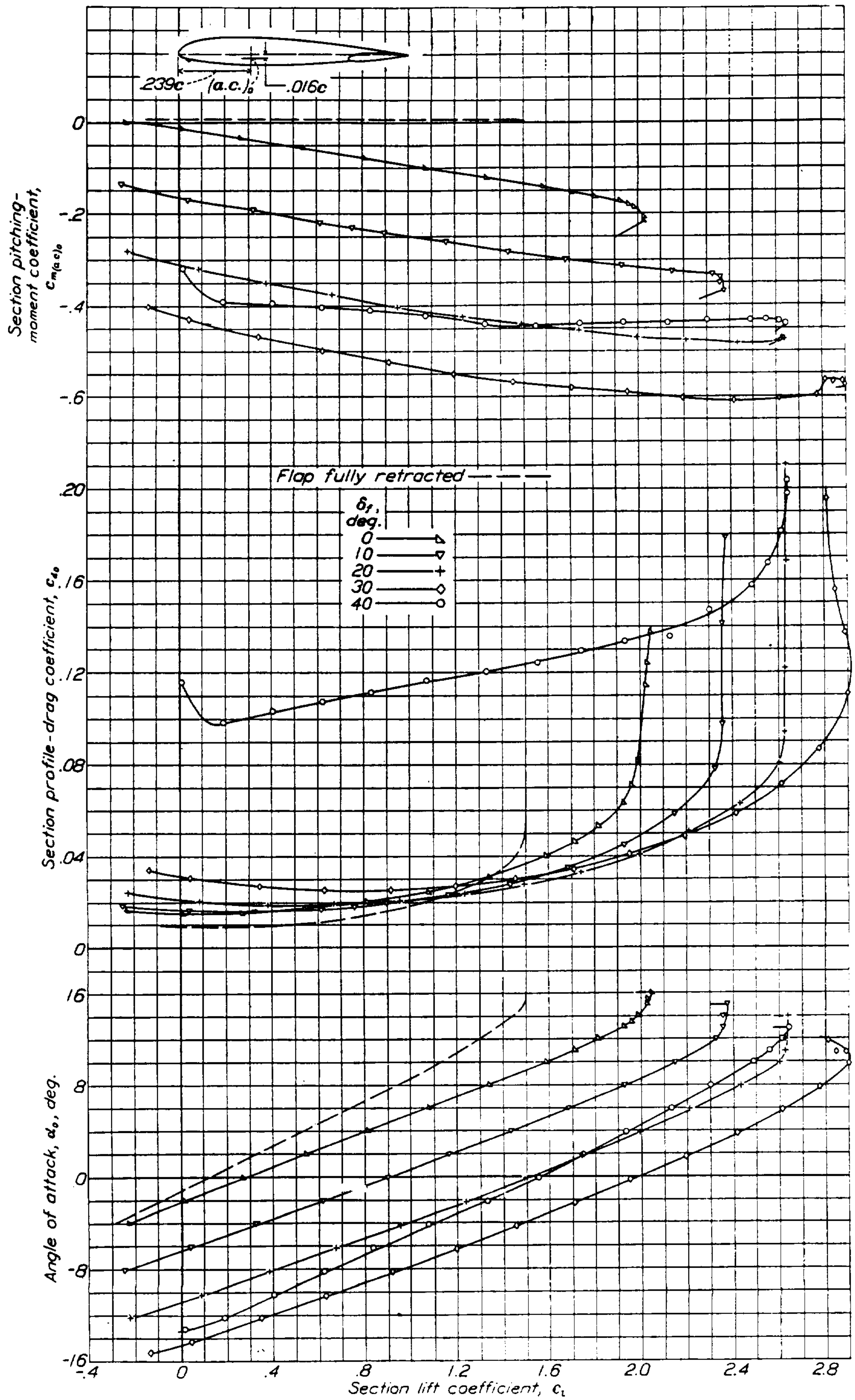


FIGURE 11.—Section aerodynamic characteristics of N. A. C. A. 23012 airfoil with a 0.2667c_w N. A. C. A. 23012 Fowler flap.

The increment of maximum lift coefficient for a given flap deflection is from 4 to 10 percent larger than the increment obtained in previous tests of a model of finite span at a much lower Reynolds Number (reference 15). The increases may be almost entirely accounted for by the difference in span loadings because the reference tests were made with a rectangular airfoil in three-dimensional flow. Increments of maximum lift coefficient of an airfoil with a split flap may be considered to be practically independent of Reynolds Number. The increment of minimum profile-drag coefficient for a given flap deflection for these tests is about 10 percent greater than for the tests of reference 15. The pitching-moment coefficients from the two-dimensional-flow tests are in good agreement with the pitching-moment coefficients given in reference 15 for the same flap deflections.

Plain flap.—The section aerodynamic characteristics of the N. A. C. A. 23012 airfoil with a 0.20c plain flap are shown in figure 9. Comparison of these results with the plain-flap results of reference 15 shows about the same differences that were observed for the split flap. The section hinge-moment coefficients given in figure 9 are of about the same magnitude as hinge-moment coefficients of a 0.20c plain flap on a Clark Y airfoil (reference 15). It should be noted that the characteristics for the plain flap with both up and down deflections are useful for the estimation of aileron as well as flap effects.

External-airfoil flap.—The section aerodynamic characteristics of the N. A. C. A. 23012 airfoil with an N. A. C. A. 23012 external-airfoil flap are given in figure 10. The relative merits of this flap arrangement are about the same as a similar arrangement tested in three-dimensional flow (reference 2) at the same effective Reynolds Number. Peculiarities in the curves of lift, profile drag, and pitching moment at the high flap deflections seem to be characteristic of this type of flap and probably indicate a marked change in flow pattern around the combination. As pointed out in reference 2, the pitching-moment coefficients with this type of flap are higher than with the split or plain flaps.

Fowler flap.—The section aerodynamic characteristics of the N. A. C. A. 23012 airfoil with an N. A. C. A. 23012 Fowler flap are given in figure 11. The data for the model with the Fowler flap fully retracted included on this figure are taken from the tests at 80 miles per hour. These results are in good agreement with previous results of tests of Fowler flaps. (See references 4 and 16.) The large pitching-moment coefficients obtained with this flap may, in a large measure, affect its use for a particular design. It is of interest to note that, with the flap fully retracted, there is no measurable increase in profile drag over that of the plain wing (fig. 7) for lift coefficients (c_l) below 0.8 but there is a loss of about 0.05 in maximum lift coefficient. The angle of attack for maximum lift with the flap set at 30° is only 10°, which is a decrease of 5° when compared with that for the plain wing. This decrease is greater than that for any of the other flap arrangements.

PRELIMINARY TESTS OF SLOTTED FLAPS

A preliminary investigation was conducted of the Handley Page slotted flap, designated flap 1, and of four slot shapes, the combinations being designated

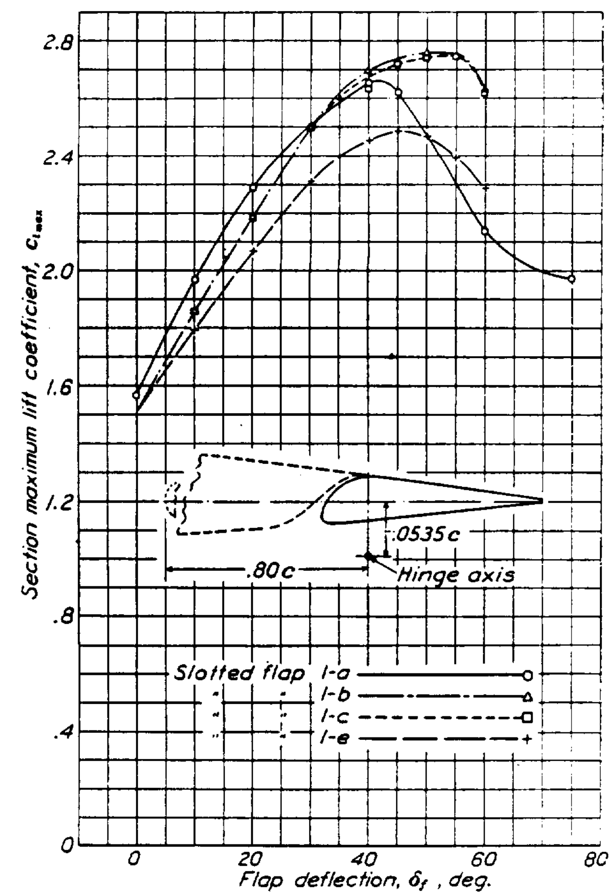


FIGURE 12.—Effect of slot shape on $c_{l_{max}}$. Flap 1 at predetermined axis location.

1-a, 1-b, 1-c, and 1-e (fig. 4). For this part of the investigation, the axis about which the flap was deflected was determined from the data of reference 8.

Effect of slot shape on maximum lift.—The maximum lift coefficients $c_{l_{max}}$ are plotted against flap deflection δ_f in figure 12 for the several slot shapes. These data show that extending the lip of the slot so that the slot is sealed at the exit when the flap is neutral (shape 1-b) gave an increase of 4 percent in maximum lift coefficient over shape 1-a. Increasing the slot-entry angle (shape 1-c) caused a very slight decrease in maximum lift coefficient. A further change in slot shape to close the gap through the airfoil with the flap neutral (shape 1-e) decreased the maximum lift coefficient 11 percent from the value obtained with slotted flap 1-b.

Effect of slot shape on profile drag.—A comparison of the envelope polars for slotted flaps 1-a and 1-b (fig. 13) shows that, for both high lift and low drag, slotted flap 1-b is superior. The higher drag of arrangement 1-a in the low-lift (high-speed) range can be accounted for by the open slot through the airfoil with the flap neutral. With the wing and the power loadings of present-day large transport airplanes, the best lift coefficient for take-off with a good slotted flap seems to be around 2.5; therefore, it is important to have as low a profile drag as possible at these high lift coefficients. It is probable that the lower drag of slotted flap 1-b at the higher lift coefficients may be accounted for by the better shape of this slot lip, which directs the air downward over the flap and prevents it from stalling at the higher flap deflections. There is no appreciable dif-

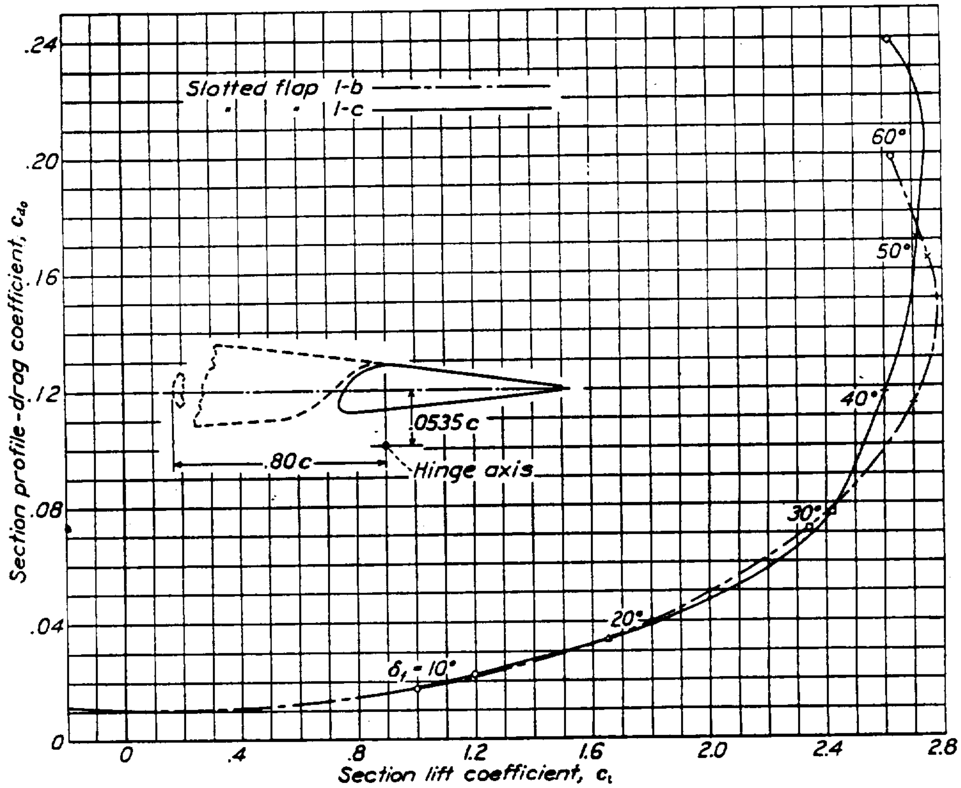


FIGURE 13.—Comparison of slotted flaps 1-a and 1-b.

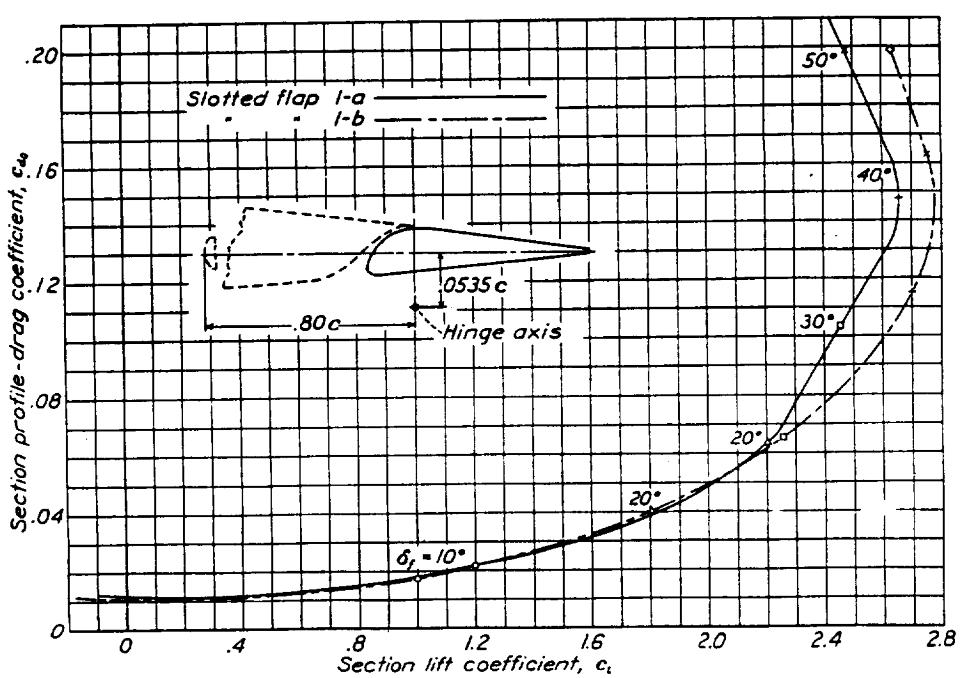


FIGURE 14.—Comparison of slotted flaps 1-b and 1-c.

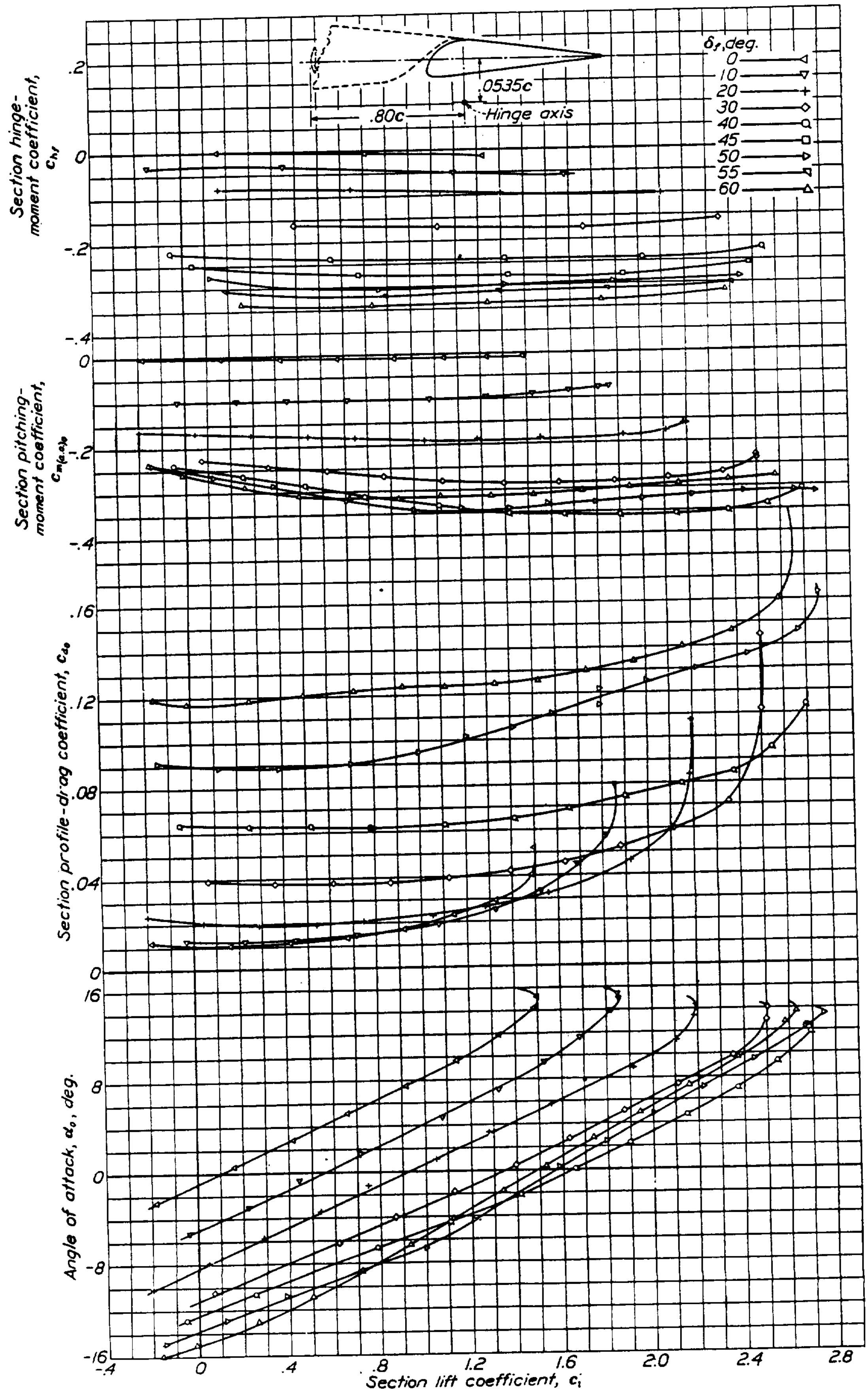
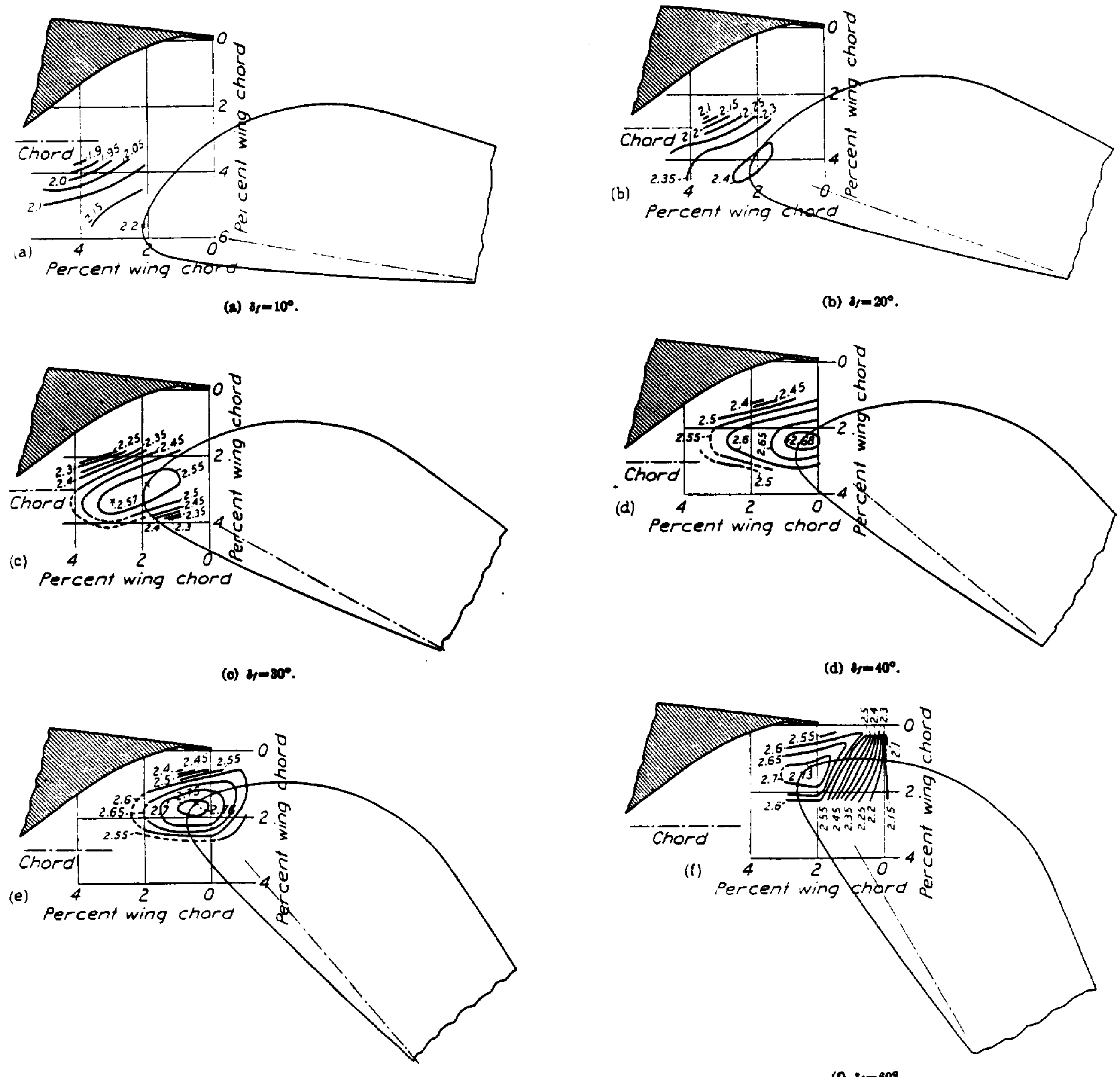


FIGURE 15.—Section aerodynamic characteristics of N. A. C. A. 23012 airfoil with slotted flap 1-b.

ference in drag between slotted flaps 1-b and 1-c up to lift coefficients of about 2.5 (fig. 14). Because of the lower maximum lift of slotted flap 1-e, the drag data for it were not obtained. Other tests of slotted flap 1-e will be discussed later.

axis location was used. The profile drag was also among the lowest. An inspection of the curves of α_0 against c_l in figure 15 shows that the slope of the lift curves is practically unaffected by flap deflection except for the very large values. As previously mentioned, compari-



(a) $\delta_f=10°$.

(b) $\delta_f=20°$.

(c) $\delta_f=30°$.

(d) $\delta_f=40°$.

(e) $\delta_f=50°$.

(f) $\delta_f=60°$.

FIGURE 16.—Contours of flap location for $c_{l_{max}}$. Slotted flap 1-b.

Complete data on slotted flap 1-b.—The complete section aerodynamic characteristics of the N. A. C. A. 23012 airfoil with slotted flap 1-b deflected downward various amounts are given in figure 15. This flap arrangement gave the highest lift coefficient of any of the four arrangements for which the Handley Page fixed-

son of the $c_{d_{0_{min}}}$ with the flap neutral with the $c_{d_{0_{min}}}$ of the plain wing (fig. 7) shows that there is a difference of about 0.001. The greater part of this increase in drag is caused by the flap hinge fittings; the remaining Δc_{d_0} is due to the break in the lower surface of the airfoil caused by the slot and will be discussed later.

The pitching-moment coefficients for this flap arrangement are about the same as for the external-airfoil flap. A small change between the pitching-moment coefficients for the flap undeflected ($\delta_f=0°$) and for the plain airfoil (fig. 7) may be attributed to a slight downward deflection of the slotted flap. The hinge-moment coefficients are about one-half as great as those for the plain flap (fig. 9) because the hinge-axis location for the slotted flap was designed to give partial balance.

DETERMINATION OF OPTIMUM SLOTTED-FLAP ARRANGEMENT FOR MAXIMUM LIFT

The data presented in this section are the results of the maximum-lift investigation of the various flap-and-slot combinations in which the flap, at a given deflection, was located at points over a considerable area with respect to the main airfoil. The data are presented as contours of the position of the nose point of the flap for a given lift coefficient. The nose point of the flap is defined as the point of tangency of a line drawn perpendicular to the airfoil chord and tangent to the leading-edge arc of the flap when neutral.

Slotted flap 1.—Contours of flap location for maximum lift coefficient for a given flap angle are given in figure 16 for flap 1–b. At 10° flap deflection (fig. 16 (a)), the area of flap positions covered was not sufficient to define the optimum position. The highest $c_{l_{max}}$ is, however, 19 percent higher than it was for flap 1–b at 10° deflection about the predetermined axis location (fig. 15). It appears that a large gap between wing and flap is desirable for low flap deflections from considerations of maximum lift. At 20° flap deflection (fig. 16 (b)), the optimum position of the nose of the flap is 4 percent below and 2 percent ahead of the slot lip. In this position, the maximum lift is 10 percent higher than it was for the combination given in figure 15. At 30° deflection (fig. 16 (c)), the optimum position of the flap for maximum lift is slightly above the position for the 20° deflection. The maximum lift is 3 percent higher with the flap in the optimum position at this deflection than it was for the same deflection about the predetermined axis location (fig. 15). The optimum position of the flap for deflections up to 30° probably should be chosen from a consideration of the drag coefficients rather than the maximum lift coefficient because the take-off distance of an airplane may be decreased by depressing the flap. It is therefore desirable that the drag coefficient be a minimum for a given lift coefficient corresponding to the lift coefficient for best climb. With the flap deflected 40° and 50° (figs. 16 (d) and (e)), the maximum lift coefficient is about the same as for the same deflections about the predetermined axis location (fig. 15). The optimum positions of the nose point of the flap for these deflections are, respectively, about 2.5 percent below and 0.5 percent ahead of the slot lip and 1.75 percent below and 0.5 percent ahead of the slot lip. For the 60° flap deflection (fig. 16 (f)), the maximum lift coefficient is about 4 percent higher than for the same deflection about the predetermined axis location (fig. 15). The optimum position of the nose point of the flap for this deflection is about 1 percent below the slot lip.

The contours of figure 16 show that, for small flap deflections, the optimum position of the flap for maximum lift coefficient is much less critical than it is for the larger flap deflections. It is also evident that there is a considerable loss in lift coefficient if the nose of the flap is moved back of the slot lip. These results are in agreement with previous tests of external-airfoil and Fowler flaps. The highest maximum lift coefficient was obtained with the nose of the flap directly under the slot lip and with a gap between the flap nose and the slot lip of about 1¾ percent of the wing chord.

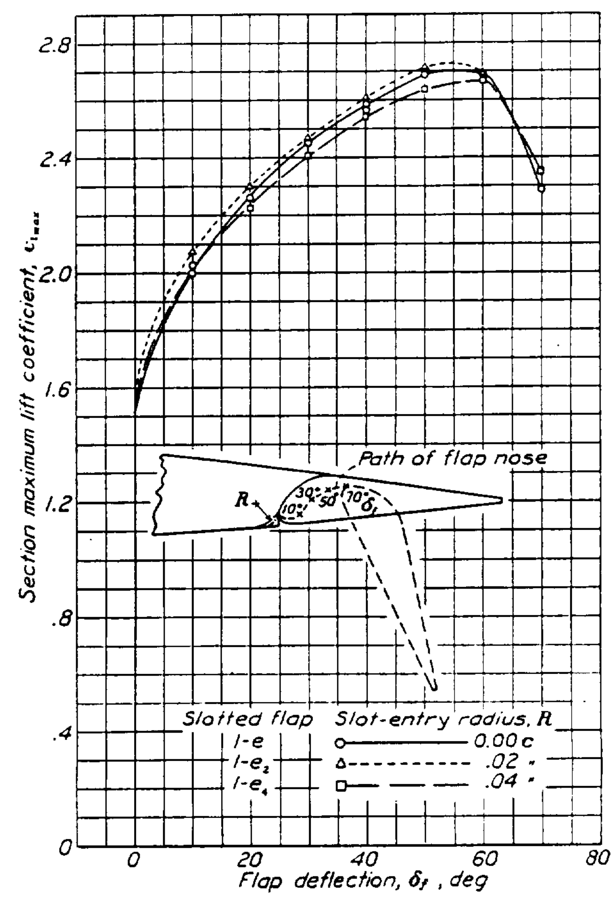


FIGURE 17.—Effect of slot-entry radius on $c_{l_{max}}$.

Because of a possible hazard from icing of large openings in the surface of a wing, flap 1 was also tested using slot shape e, with the flap in the best position for maximum lift coefficient from the tests of shape b. The results of these tests are given in figure 17 as plots of maximum lift coefficient against flap deflection. The effect of rounding the slot entry on maximum lift coefficient is also shown in this figure. The maximum lift coefficient of slotted flap 1–e from these tests is about 8 percent higher than it was for this combination with the flap deflected about the predetermined axis location (fig. 12). With the slot entry rounded to a radius 2 percent of the wing chord (slotted flap 1-e_2), the maximum lift coefficient is about the same as it was for slotted flap 1-b (fig. 16 (f)). A further rounding of the slot entry to a 4-percent-chord radius had a detrimental effect on the maximum lift. It appears from these results that the shape of the slot is not critical for maximum lift provided that the flap is located properly with respect to the slot lip.

Slotted flap 2.—The contours showing maximum lift coefficients for the various deflections of slotted flap 2-h are given in figure 18. This combination gives a higher lift coefficient at each deflection than was obtained at the corresponding flap deflections with flap 1-b (fig. 16). The total projected area of flap 2-h and the main airfoil is greater than the area of the combination with flap 1-b, which accounts for the increases in lift. The best positions for the nose of flap 2-h relative to the slot lip are practically the same as for flap 1-b.

The contours showing the maximum lift coefficients for the various deflections of slotted flap 2-i are given in figure 19. This arrangement is inferior to both 1-b and 2-h throughout the complete range of flap deflections. The maximum lift coefficient was obtained with the flap deflected 60°, which is 10° greater than for either flap 1-b or flap 2-h. The maximum lift coefficient with flap 2-i is about the same as it was for flap 1-e_2 (fig. 17), a comparable arrangement. The position of the flap nose for maximum lift coefficient for this arrangement is only about 0.5 percent of the chord below and about 0.25 percent back of the slot lip.

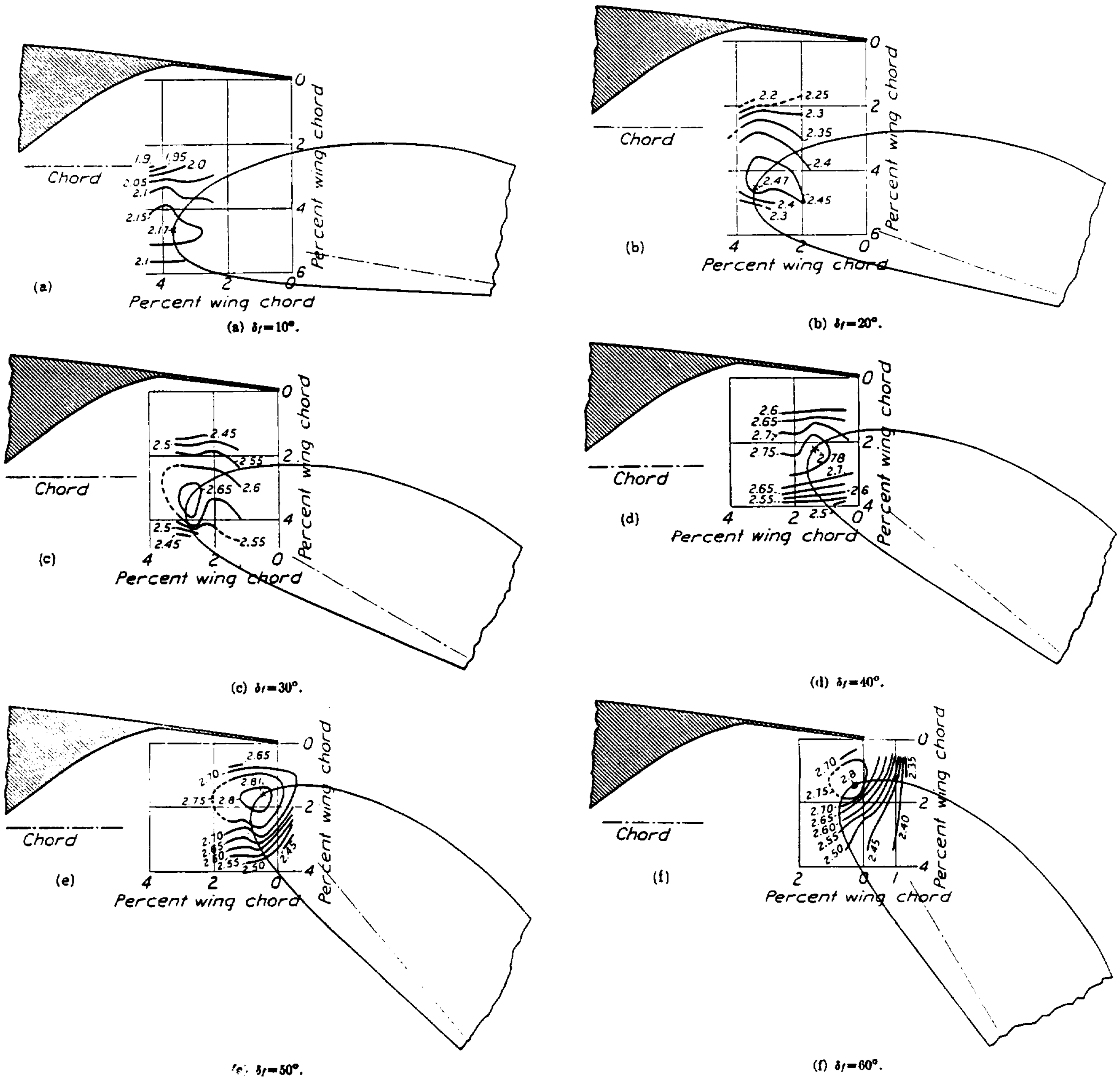
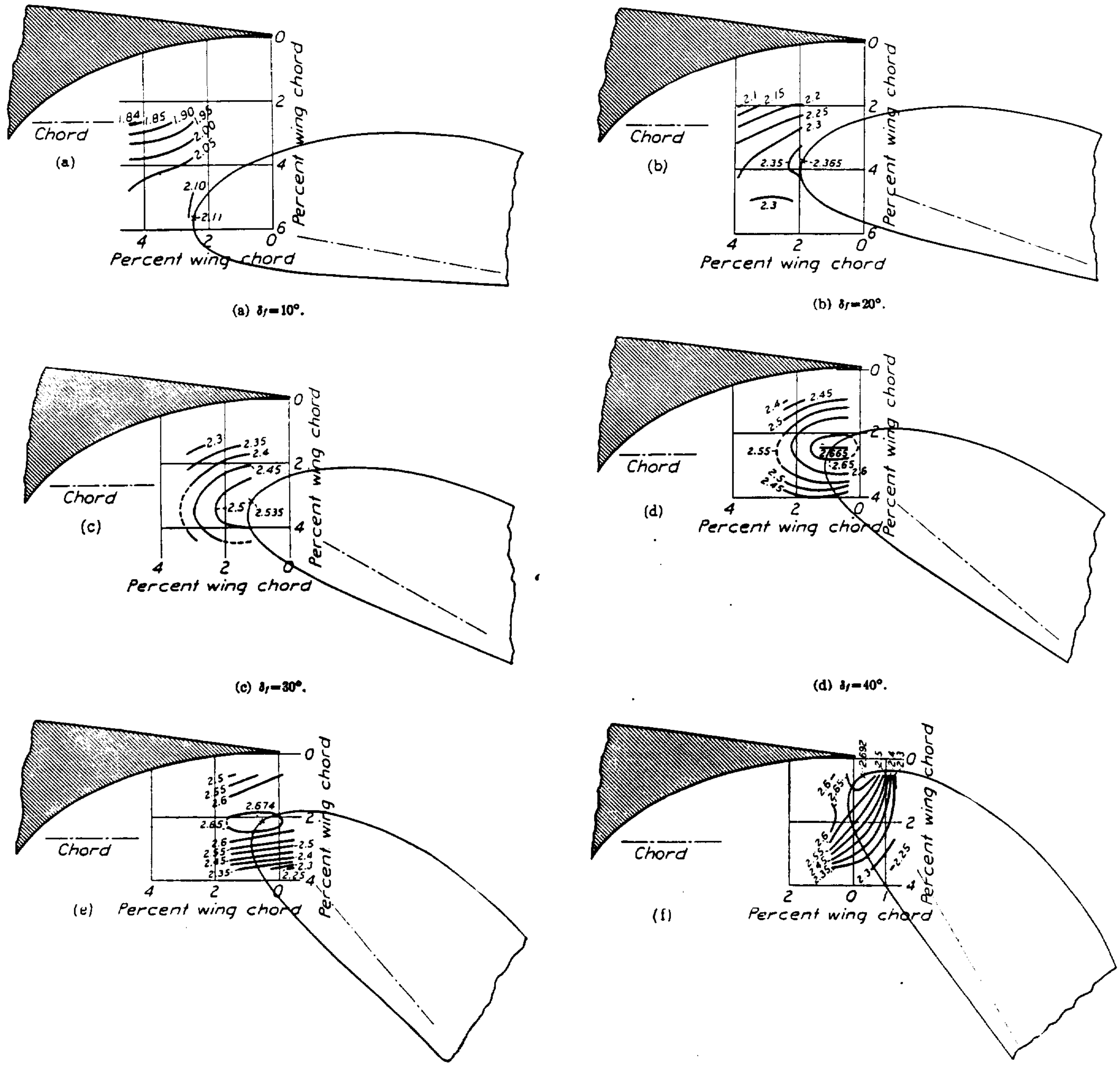


FIGURE 18.—Contours of flap location for $c_{l_{max}}$. Slotted flap 2-h.



(a) $\delta_f=10°$. (b) $\delta_f=20°$.

(c) $\delta_f=30°$. (d) $\delta_f=40°$.

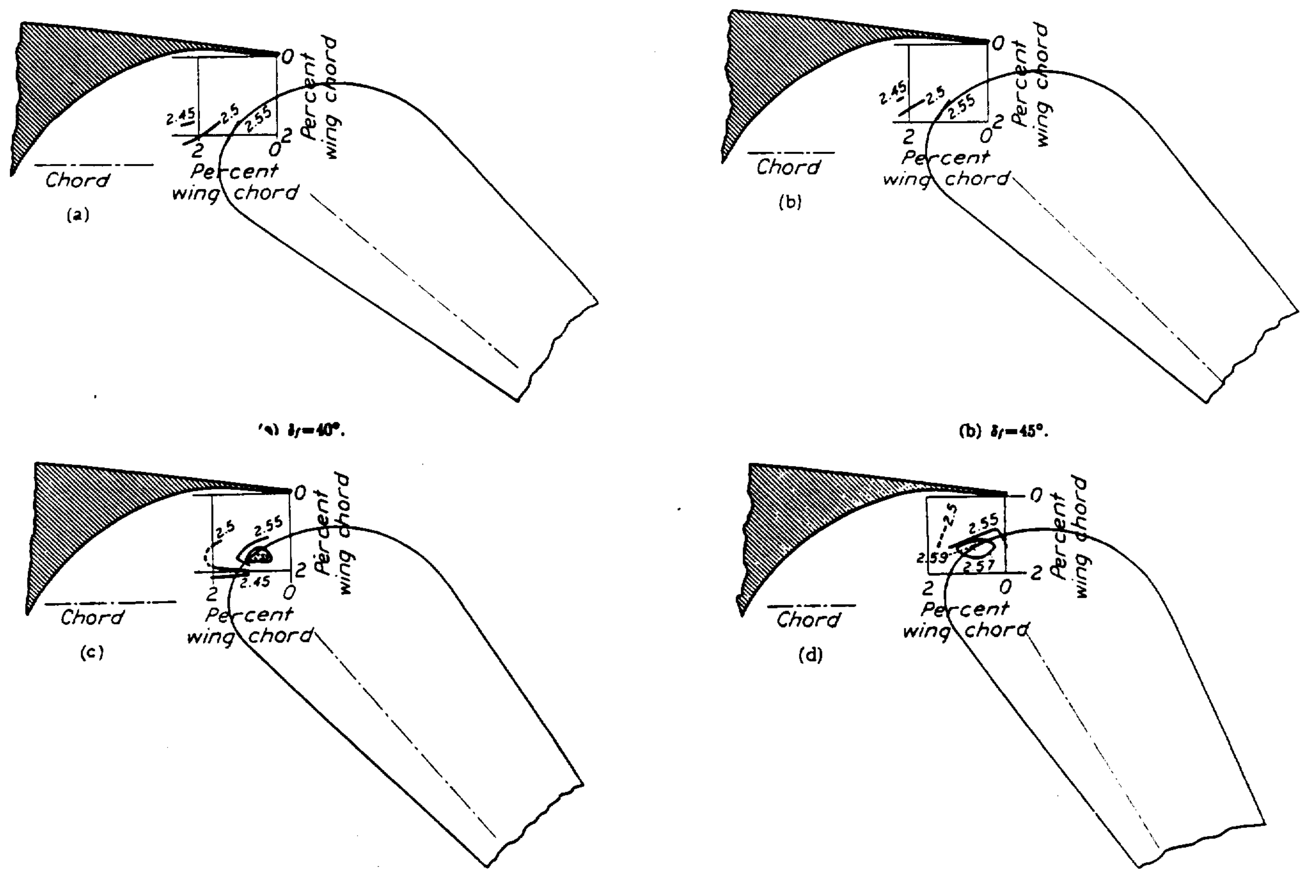
(e) $\delta_f=50°$. (f) $\delta_f=60°$.

FIGURE 19.—Contours of flap location for $c_{l_{max}}$. Slotted flap 2-1.

Slotted flap 3.—Contours of the flap-nose position for the maximum lift coefficients of slotted flaps 3-f and 3-g are given in figures 20 and 21, respectively. Both of these flaps are inferior to all the other slotted-flap combinations tested, and both have about the same maximum lift coefficient. No tests were made at the small flap deflections because of the inferiority of the flaps at the large flap deflections. The nose shape of this flap is probably too blunt to obtain a satisfactory flow of the air over the upper surface of the flap.

EFFECT ON PROFILE DRAG OF BREAK IN AIRFOIL SURFACE DUE TO SLOT

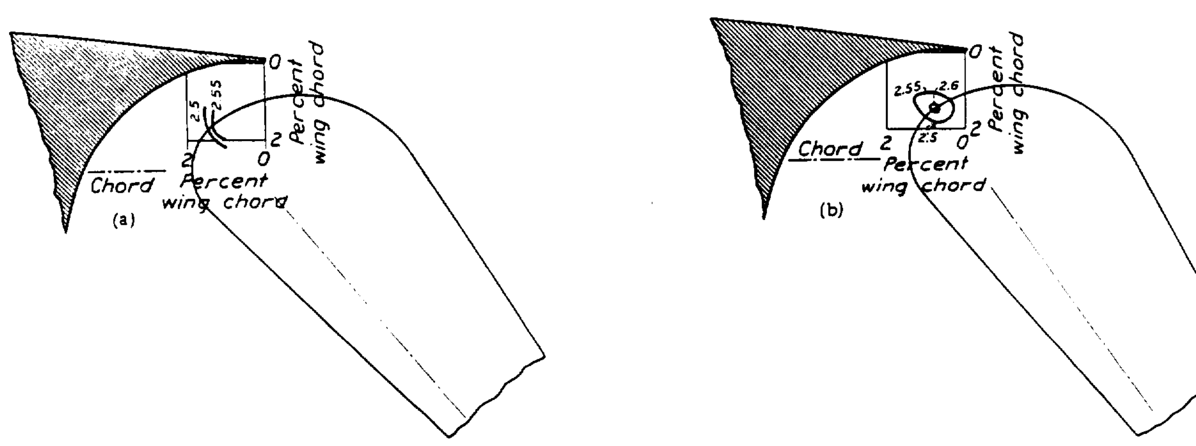
The increments of profile drag Δc_{d_0} caused by the breaks in the airfoil surface at the flap are plotted in figure 22. These data were obtained by making tests with the flap undeflected both with and without the breaks in the surface. (The breaks in the surface were sealed with plasticine for the tests without the breaks.) The curves given in figure 22 are differences between faired curves through the test points for the individual tests. Slotted flap 1–a, which has an open slot through the airfoil with the flap undeflected, gave the largest increment of profile-drag coefficient for all lift coefficients up to 0.60. At the higher lift coefficients, the Δc_{d_0} decreases probably because of some boundary-layer control from the air ejected on the upper surface of the airfoil. The Δc_{d_0} for slotted flaps 1–b and 2–h increased from about 0.0008 at zero lift to about 0.0013 at a lift coefficient of 1.0. At zero lift, slotted flap 1–e_4 gave a Δc_{d_0} of 0.0004, which increased to 0.0009 at the higher lift coefficients. Slotted flaps 1–e_2 and 2–i are the next in order giving, at zero lift, a Δc_{d_0} of 0.0003 increasing nearly to 0.0008 at the higher lift coefficients. Slotted flap 1–e gave a Δc_{d_0} of about 0.0001 for the low-lift condition, which increased nearly to 0.0003 at a lift coefficient of about 0.50 and then decreased to zero at higher lift coefficients. Slotted flap 1–c showed no increase in profile drag. It should be pointed out



(a) $\delta_f=40°$. (b) $\delta_f=45°$.

(c) $\delta_f=50°$. (d) $\delta_f=60°$.

FIGURE 20.—Contours of flap location for $c_{l_{max}}$. Slotted flap 3–f.



(a) $\delta_f=50°$. (b) $\delta_f=55°$.

FIGURE 21.—Contours of flap location for $c_{l_{max}}$. Slotted flap 3–g.

that a Δc_{d_0} less than 0.0003 is too small to measure definitely because such a small value is within the experimental accuracy of the tests.

DETERMINATION OF THE OPTIMUM SLOTTED-FLAP ARRANGEMENT FOR PROFILE DRAG

The results presented in this section are intended to aid in the determination of the optimum positions of the several slotted flaps for take-off and climb from considerations of low drag. The best take-off and climb to clear a specified height in the shortest horizontal distance will be the lowest drag coefficient at the lift coefficients corresponding to take-off and climb. The data are therefore given as contours of the nose position of the flap for constant drag coefficients at certain selected lift coefficients that cover the range for which the drag coefficient is decreased by deflecting the flap. The data previously presented show that, for

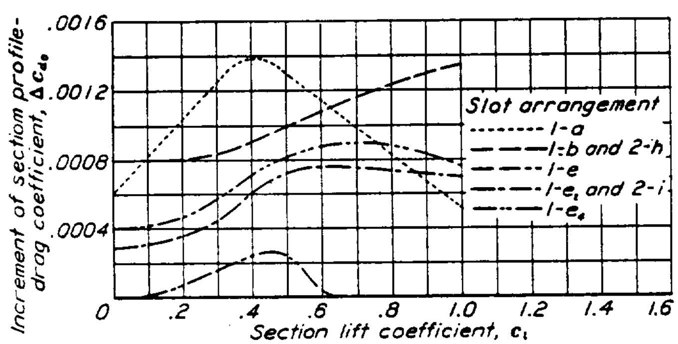
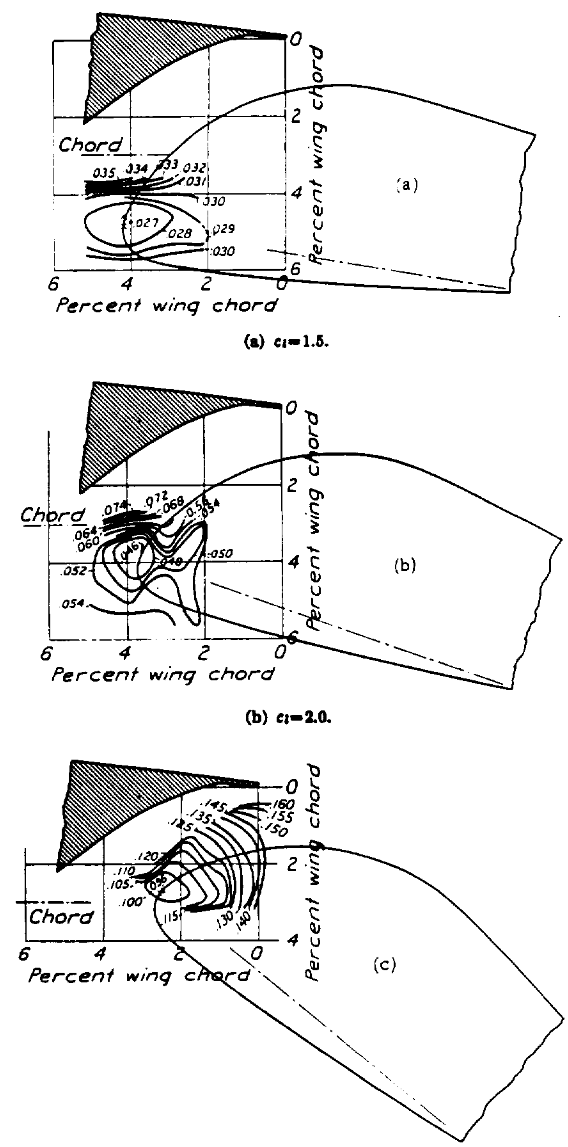


FIGURE 22.—Effect of slot openings in surface of airfoil on increments of profile drag. δ_f, 0°; effective Reynolds Number, 3,500,000.

lift coefficients of 1.0 or less, the drag is lowest with the flap undeflected.

Slotted flap 1.—The contours of the position of the nose point of slotted flap 1–b for constant c_{d_0} are given in figure 23. The best position for this flap at a lift coefficient of 1.5 (fig. 23 (a)) is with the nose point of the flap 5 percent of the chord below and 4 percent of the chord ahead of the slot lip. The minimum profile-drag coefficient is 0.027, and the position for drag coefficients up to 0.028 is not very critical. At a lift coefficient of 2.0 (fig. 23 (b)), the best position is about 1 percent above and much more critical than the best position for a lift coefficient of 1.5. The minimum profile-drag coefficient is 0.046 with the flap in the best position at a lift coefficient of 2.0. The optimum position of the nose of the flap, for minimum drag at a lift coefficient of 2.5 (fig. 23 (c)), is 2.5 percent below and 2.5 percent of the chord ahead of the slot lip. The minimum profile-drag coefficient, when the flap is in this position, is 0.096 and the position for the low drag is very much more critical than at the lower lift coefficients. The flap angles for minimum profile drag at c_l=1.5, 2.0, and 2.5 are, respectively, about 15°, 22°, and 30°.

No detailed surveys were made with slotted flap 1–e, but the effect on c_{d_0} of rounding the slot entry is shown in figure 24 as envelope polars. Rounding the slot entry with a radius 2 percent of the wing chord gives



(a) c_l=1.5.

(b) c_l=2.0.

(c) c_l=2.5.

FIGURE 23.—Contours of flap location for c_{d_0}. Slotted flap 1-b.

a considerable decrease in c_{d_0} at all values of the lift coefficient. When the entry radius is increased to 4 percent of the wing chord, however, there is no further decrease in c_{d_0} but a considerable increase at the high lift coefficients. The best arrangement of slot shape e, slotted flap 1–e₂, is inferior to slotted flap 1–b throughout the complete range of flap deflections.

Slotted flap 2.—The contours of the position of the nose point of slotted flap 2-h for constant c_{d_0} are given in figure 25. At $c_l=1.5$ (fig. 25 (a)), the minimum profile-drag coefficient is about 4 percent less than it was for slotted flap 1-b. The position of the flap nose for the minimum profile-drag coefficient is not very critical and the tests did not cover a sufficient area to close any of the contours. For $c_l=2.0$ (fig. 25 (b)), the minimum profile-drag coefficient is about 8 percent lower than for slotted flap 1-b. The contours are not closed for this lift coefficient and the position for minimum profile drag is again not very critical. The contours of profile-drag coefficient at $c_l=2.5$ (fig. 25 (c)) show the minimum to be 25 percent less than it was for slotted flap 1-b. The position of the flap nose for minimum profile drag is critical at about 3.5 percent below and 3.0 percent of the wing chord ahead of the slot lip. There is, however, a second region of low drag farther ahead and closer to the slot upper boundary for which the contours are not closed. The preceding comparison of slotted flap 1-b and 2-h shows arrangement 2-h to be superior throughout, probably because of the better nose shape of the flap.

The contours of the position of the nose point of slotted flap 2-i for given profile-drag coefficients are shown in figure 26. A comparison of these contours with those for slotted flap 1-b (fig. 23) and 2-h (fig. 25) shows flap 2-i to be inferior to both of the others throughout the lift range. It is therefore apparently necessary that the slot have an easy entry in order to have low drag together with high lift.

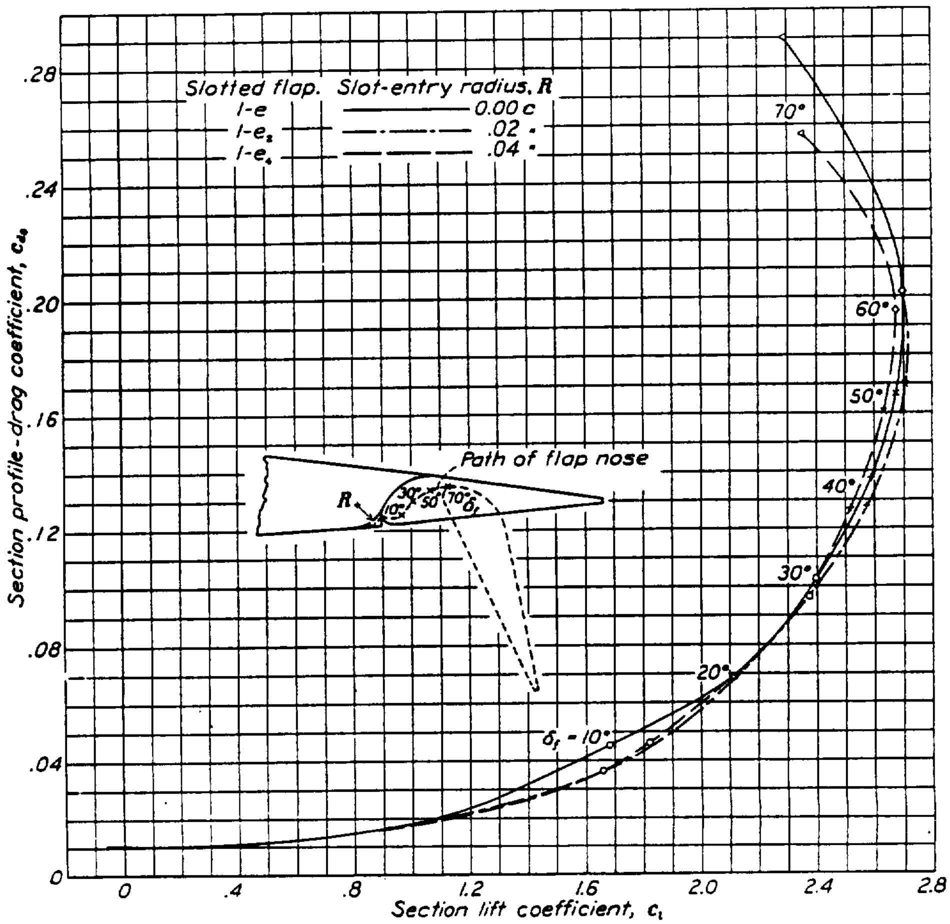
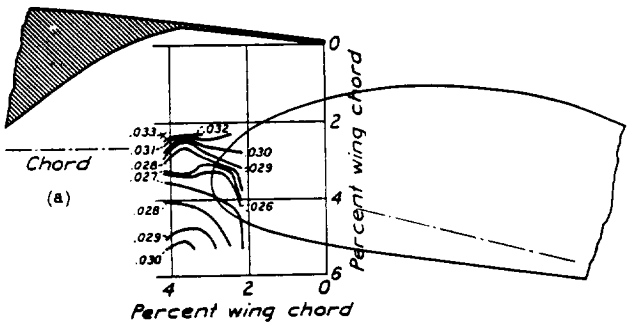


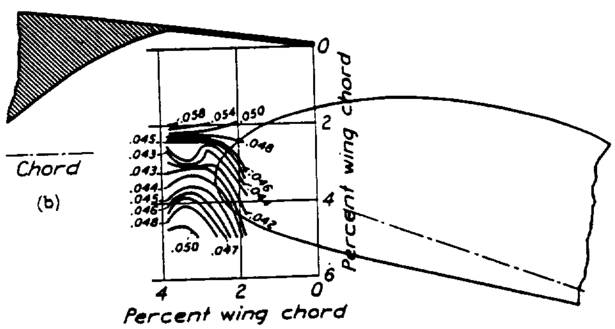
FIGURE 24.—Effect of slot-entry radius on c_{d_0}.

EFFECTS OF SLOTTED FLAP WITH SPLIT FLAP

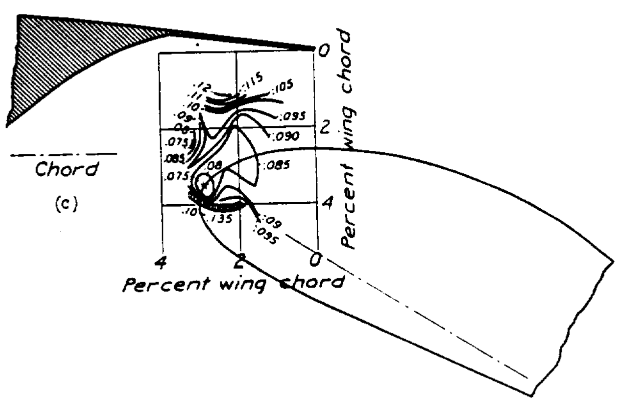
Effect on maximum lift.—The effect on $c_{l_{max}}$ of the addition of a $0.05c_w$ split flap, deflected downward 60°, to slotted flap 1-b is shown in figure 27. This comparison was made with the slotted flap hinged in such a way that it was in the optimum position for the maximum lift coefficient when deflected downward 60° without the split flap. The increase in maximum lift coefficient for small deflections of the combination is quite large. The maximum lift coefficient with the combination down 25° is the same as it is with slotted flap 1-b alone down 50°. The maximum lift coefficient with the combination down 50° is, however, only 2 percent higher than for the slotted flap alone in its opti-



(a) $c_l=1.5$.



(b) $c_l=2.0$.

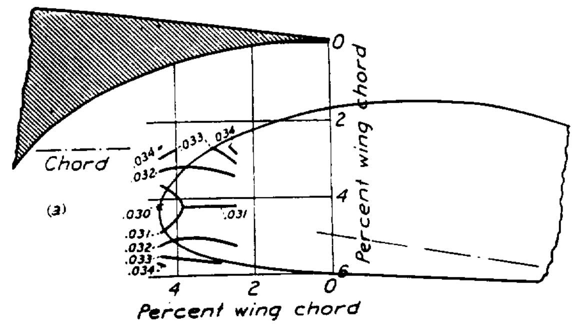


(c) $c_l=2.5$.

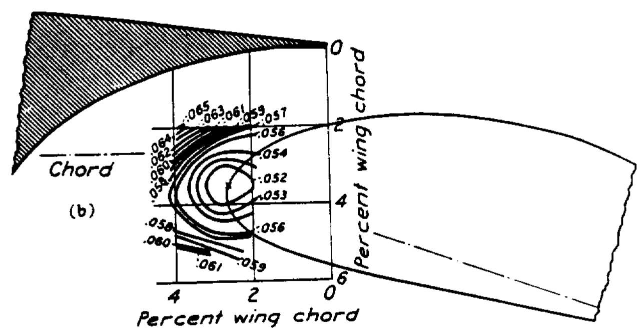
FIGURE 25.—Contours of flap location for c_{d_0}. Slotted flap 2-h.

mum position. It is possible, however, that higher maximum lift coefficients may be obtained by a more comprehensive investigation.

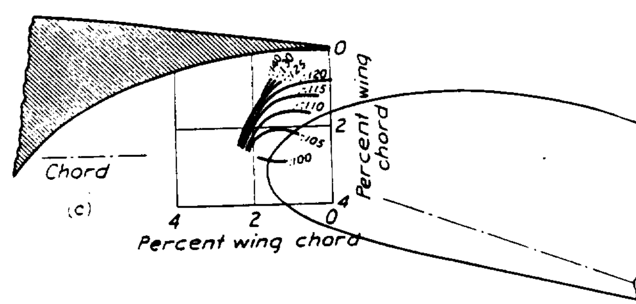
Effect on profile drag.—The effect on c_{d_0} of the addition of the split flap to slotted flap 1-b is shown in figure 28 by envelope polars. The combination has higher drag than the slotted flap alone for lift coefficients less than 2.2. It is possible, however, that lower drags could be obtained by using smaller deflections of the split flap at the smaller deflections of the slotted flap. The combination has a lower drag than the slotted flap alone at lift coefficients above 2.2. These results indi-



(a) $c_l=1.5$.



(b) $c_l=2.0$.



(c) $c_l=2.5$.

FIGURE 26.—Contours of flap location for c_{d_0}. Slotted flap 2-i.

cate that multiple-slot flaps might be developed which would be superior, from considerations of low drag for take-off and high lift for landing, to any of the slotted flaps investigated. Further investigation is recommended of multiple-slot flaps and of slotted flaps in combination with plain and with split flaps.

OPTIMUM ARRANGEMENT OF SLOTTED FLAP

The optimum flap arrangement was chosen on the basis of minimum profile-drag coefficient at a given lift coefficient for lift coefficients less than 2.5 and of maximum lift coefficient for the larger flap deflections. On this basis, slotted flap 2-h was superior to any of the other flap combinations tested. The data for slotted flap 2-h, when moved along the optimum path shown, are given in figure 29. Flap-load and moment data from pressure-distribution tests will be available for this combination at a later date.

COMPARISON OF FIVE TYPES OF FLAP

Effect on maximum lift.—Increments of maximum lift coefficient $\Delta c_{l_{max}}$ are plotted in figure 30 against flap deflection to show how the effect of flap deflection upon maximum lift varies with the five types of flap tested; namely, split, plain, external-airfoil, Fowler, and slotted flap 2-h. All coefficients are, of course, based on area with the flap neutral and the increments, except for the external-airfoil flap, are taken from the $c_{l_{max}}$ of the plain wing.

It is evident that the two slotted types which give increased area in the deflected positions give the highest maximum-lift increments. The values for slotted flap 2-h are somewhat lower than for the Fowler flap. The Fowler flap, however, may be considered as a special case of the slotted flap in which the

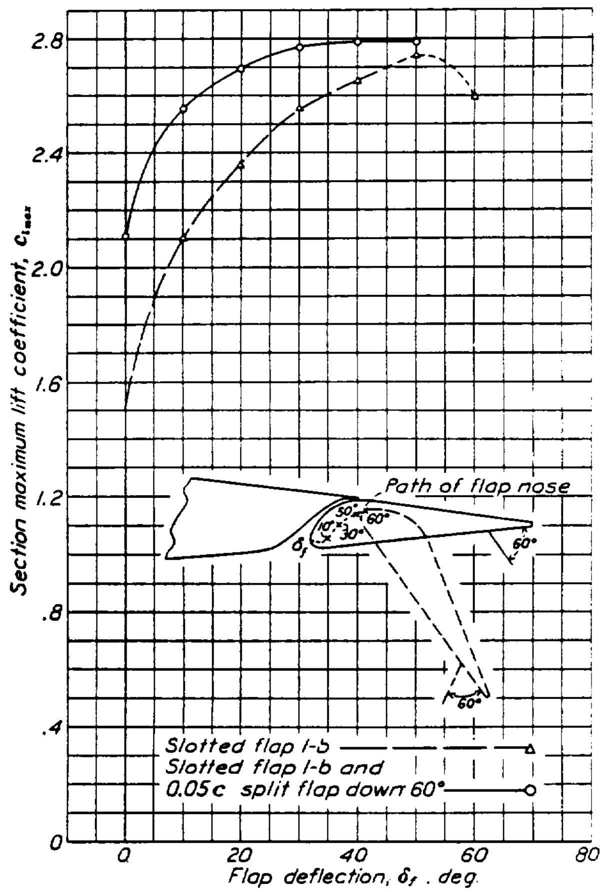


FIGURE 27.—Effect on $c_{l_{max}}$ of combining split flap with slotted flap. Slotted flap 1-b.

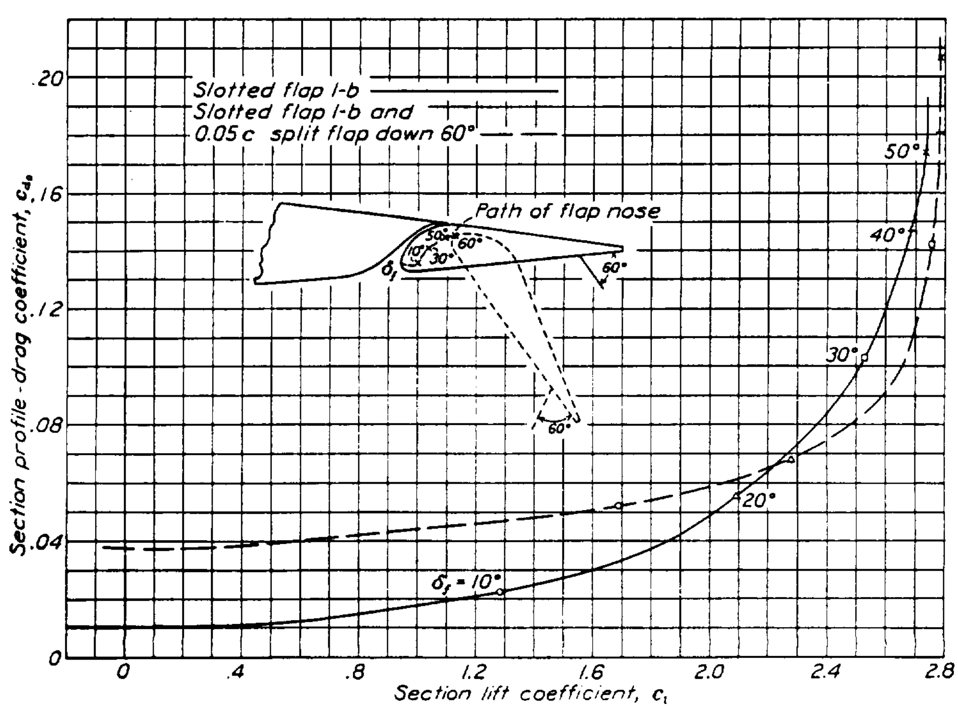
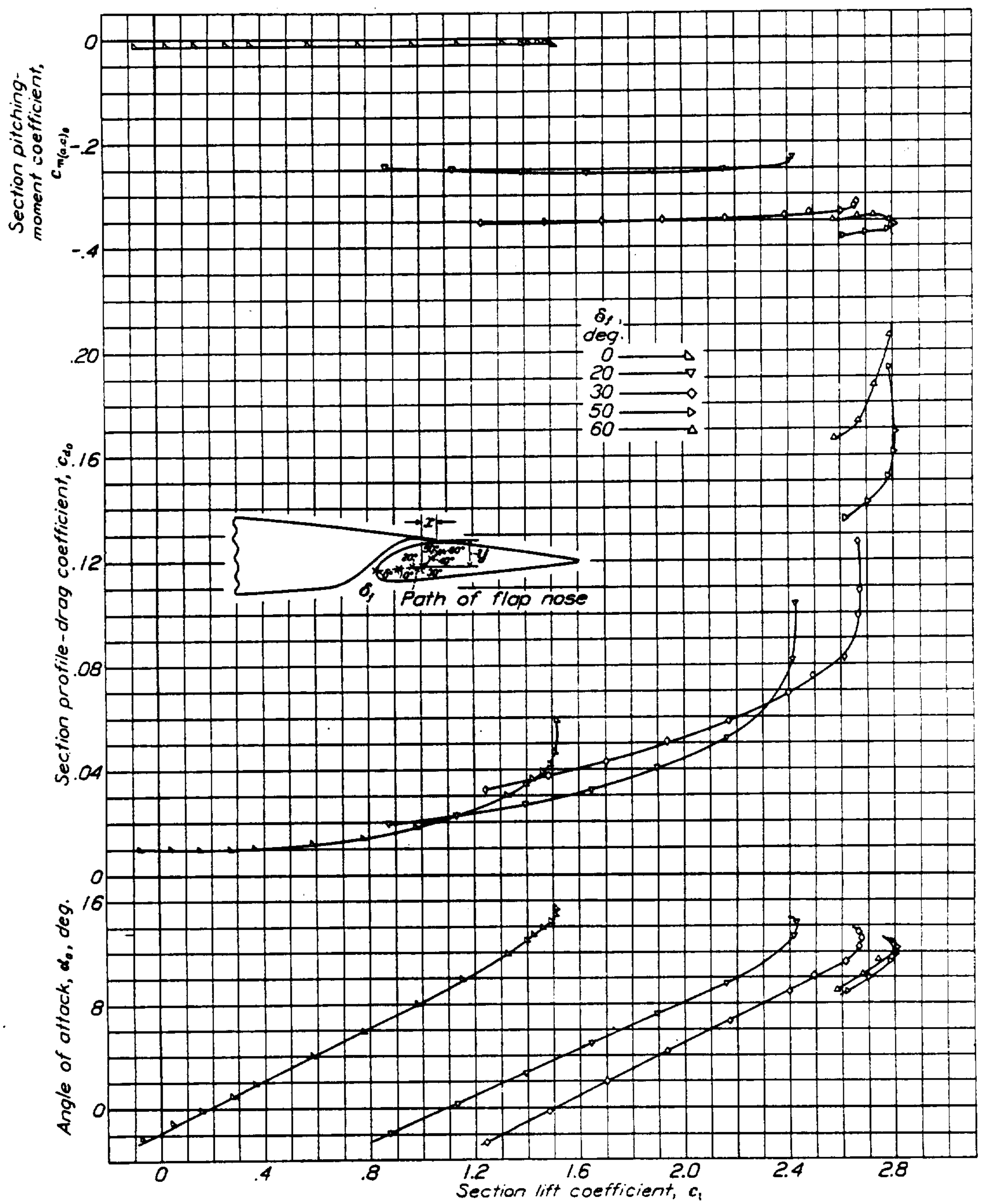


FIGURE 28.—Effect on c_{d_0} of combining split flap with slotted flap. Slotted flap 1-b.



Path of flap nose for various flap deflections. Distances measured from lower edge of lip in percent airfoil chord c

δ_f (deg.)	x	y
0	8.36	3.91
10	5.41	3.63
20	3.83	3.45
30	2.63	3.37
40	1.35	2.43
50	.50	1.63
60	.12	1.48

FIGURE 29.—Section aerodynamic characteristics of N. A. C. A. 23012 airfoil with slotted flap 2-h.

lip of the slot is extended to the trailing edge of the basic airfoil. The flap is therefore moved through a greater distance when extended and deflected and, consequently, gives more lift because of the greater lifting surface exposed to the air. Slotted flaps could be developed with the slot lip terminated at any point between the location for slotted flap 2-h, or farther forward, and the trailing edge of the airfoil. These slotted flaps would be expected to give $c_{l_{max}}$ increases corresponding to the increased airfoil area.

Effect on profile drag.—The effect on c_{d_0} of the five types of flap is shown in figure 31 by envelope polars. The five types of flap have about the same profile-drag coefficients for lift coefficients less than 0.90. The airfoil with slotted flap 2-h has the lowest profile drag for lift coefficients from about 1.0 to 1.7. The airfoil with the Fowler flap is somewhat better than slotted flap 2-h as regards low profile drag at lift coefficients greater than 1.7. Here again it is probable that a slotted flap with a greater lip extension could be developed to give an even lower drag at high lift coefficients.

When the horizontal distance to land over a given obstacle is restricted, if a high drag together with a high lift is desirable, slotted flap 2-h is superior to the four other types of flap tested.

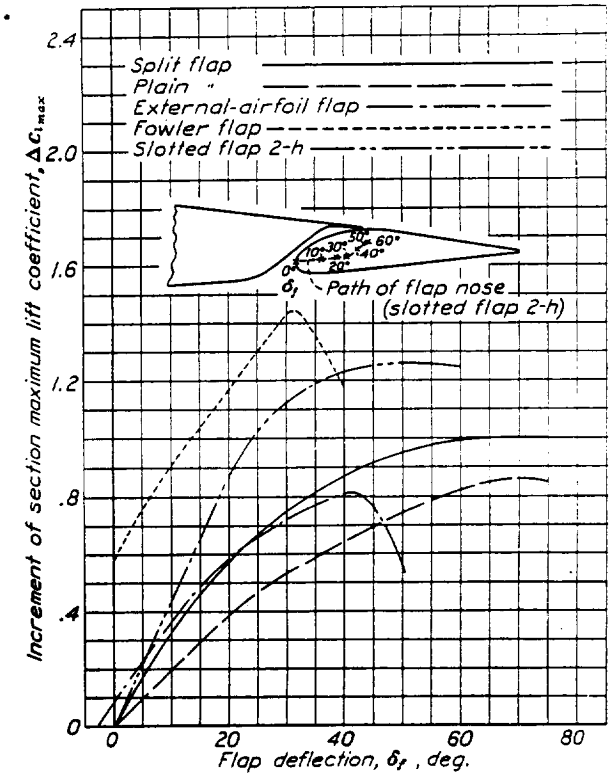


FIGURE 30.—Comparison of increments of maximum lift coefficients for five types of flap.

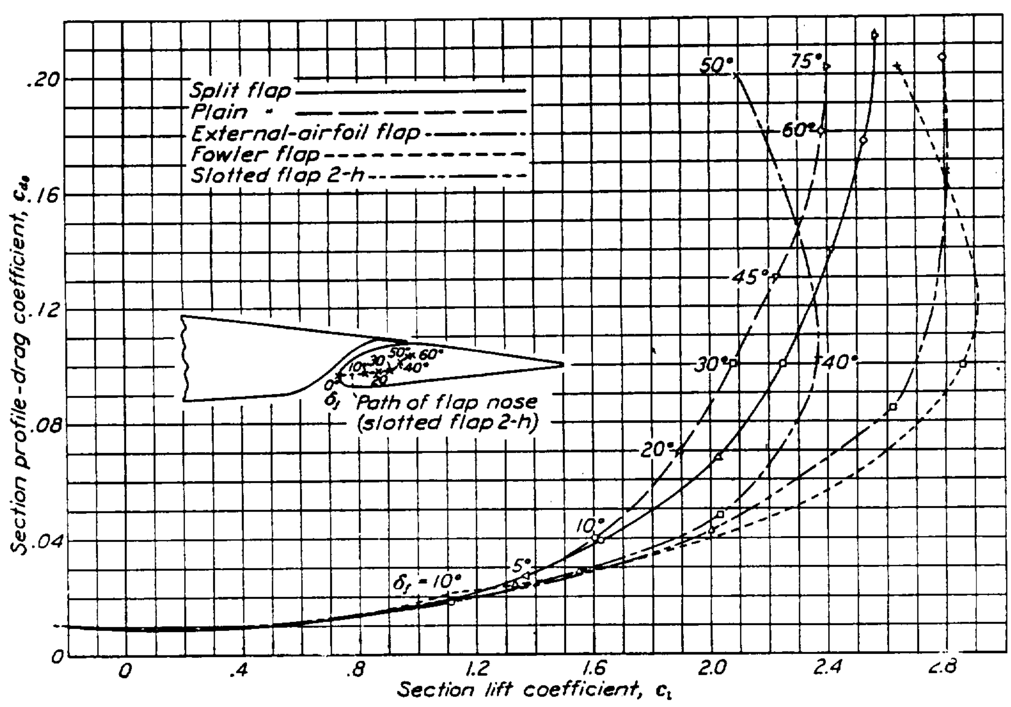


FIGURE 31.—Comparison of profile-drag coefficients for five types of flap.

II. TESTS IN VARIABLE-DENSITY WIND TUNNEL

APPARATUS AND TESTS

The variable-density wind tunnel is described in reference 17, except that an automatic electric balance has been installed to measure force coefficients. The precision is discussed in references 14 and 18.

The basic airfoil was made of duralumin to the N. A. C. A. 23012 profile. The 25.66-percent-chord slotted flap was built of brass to the ordinates given for flap 2 in table II. The shape of the slot and the positions of the flap for the various flap deflections (δ_f) are shown in figure 32. In the investigation made in the 7- by 10-foot tunnel, these positions were selected as the optimum, the criterion being low drag in the lift range below a value of 2.5 and high maximum lift above this range.

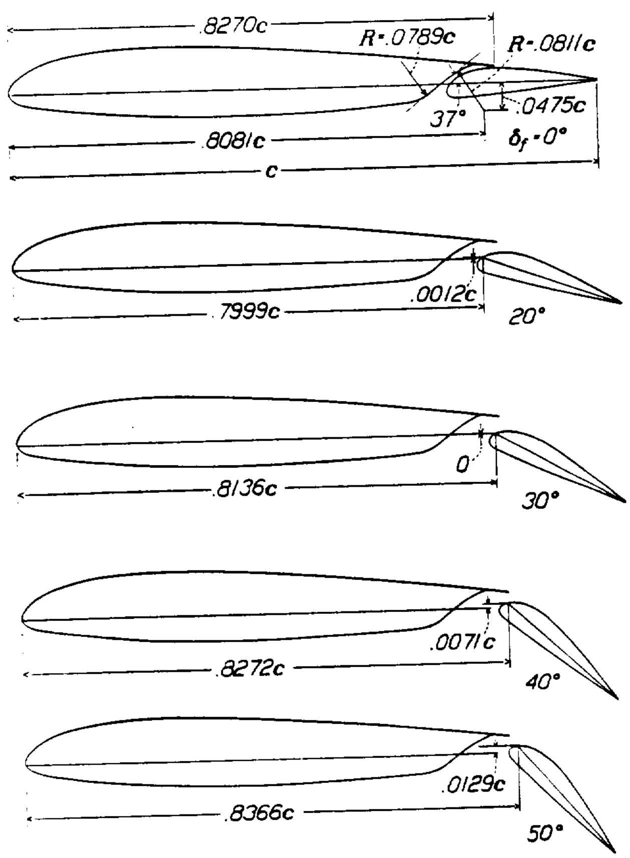


FIGURE 32.—Sections of airfoil with 0.2566c slotted flap 2-h.

The flap was attached to the wing by five small steel brackets; a different set of brackets was made for each flap position because the position was determined by the size and the shape of the brackets.

The 60-percent-chord plain flap (fig. 33) was built by cutting the wing at the 40-percent station and connecting the two parts by a narrow flexible plate flush with the lower surface. When the flap was deflected, the V-shape groove formed on the upper surface at the 40-percent point was filled with plaster of paris, forming a fair and rounded juncture.

The lift, the drag, and the pitching moment were measured from below zero lift to beyond maximum lift at an effective Reynolds Number of about 8,000,000. The lift in the region of maximum lift was also measured at an effective Reynolds Number of about 3,800,000. The measurements were made at flap settings of 0°, 20°, 30°, 40°, and 50°. In addition, at flap settings of 30° and 40°, the Reynolds Number range from 900,000 to 8,000,000 was covered.

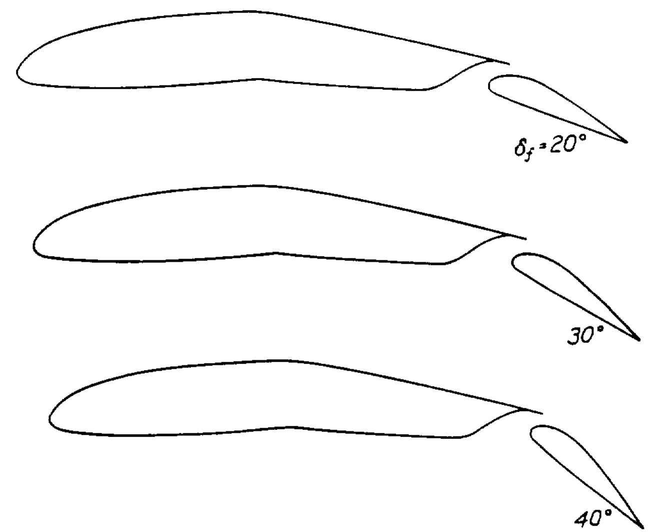


FIGURE 33.—Sections of airfoil with 0.60c plain flap deflected 12° and 0.2566c slotted flap 2-h.

The slotted flap was also tested at deflections of 20°, 30°, and 40° in combination with the 60-percent-chord plain flap deflected 12°.

RESULTS AND DISCUSSION

PRESENTATION

The results are presented as a series of lift curves for a rectangular wing of aspect ratio 6 in figure 34; the two groups of curves in the figure correspond to the two Reynolds Numbers at which all the tests were run.

The section characteristics, indicated by lower-case letters and presented in figures 35 and 36, were worked up as explained in reference 18.

MAXIMUM LIFT

The lift reaches a maximum at a flap deflection of 40° (fig. 34). The variation with Reynolds Number is shown in figure 37. The maximum lift increases with Reynolds Number but appears to be leveling off at the end of the Reynolds Number range tested (about 8,000,000). The results of tests in the 7- by 10-foot wind tunnel are also shown on the figure and the agreement with the variable-density-tunnel results, for the two points shown, is good. It will be noted that the increment of maximum lift is nearly constant over the range tested. A comparison of these results with those of references 2 and 19 shows that, at a Reynolds Number of 8,000,000, the slotted flap can reach a maximum lift coefficient of 2.86 as compared with 2.54 for the split flap, 2.39 for the plain flap, and 2.37 for the external-airfoil flap.

The deflection of the 0.60c plain flap had only a minor effect on either the maximum lift or the shape of the lift curve near the maximum (fig. 34).

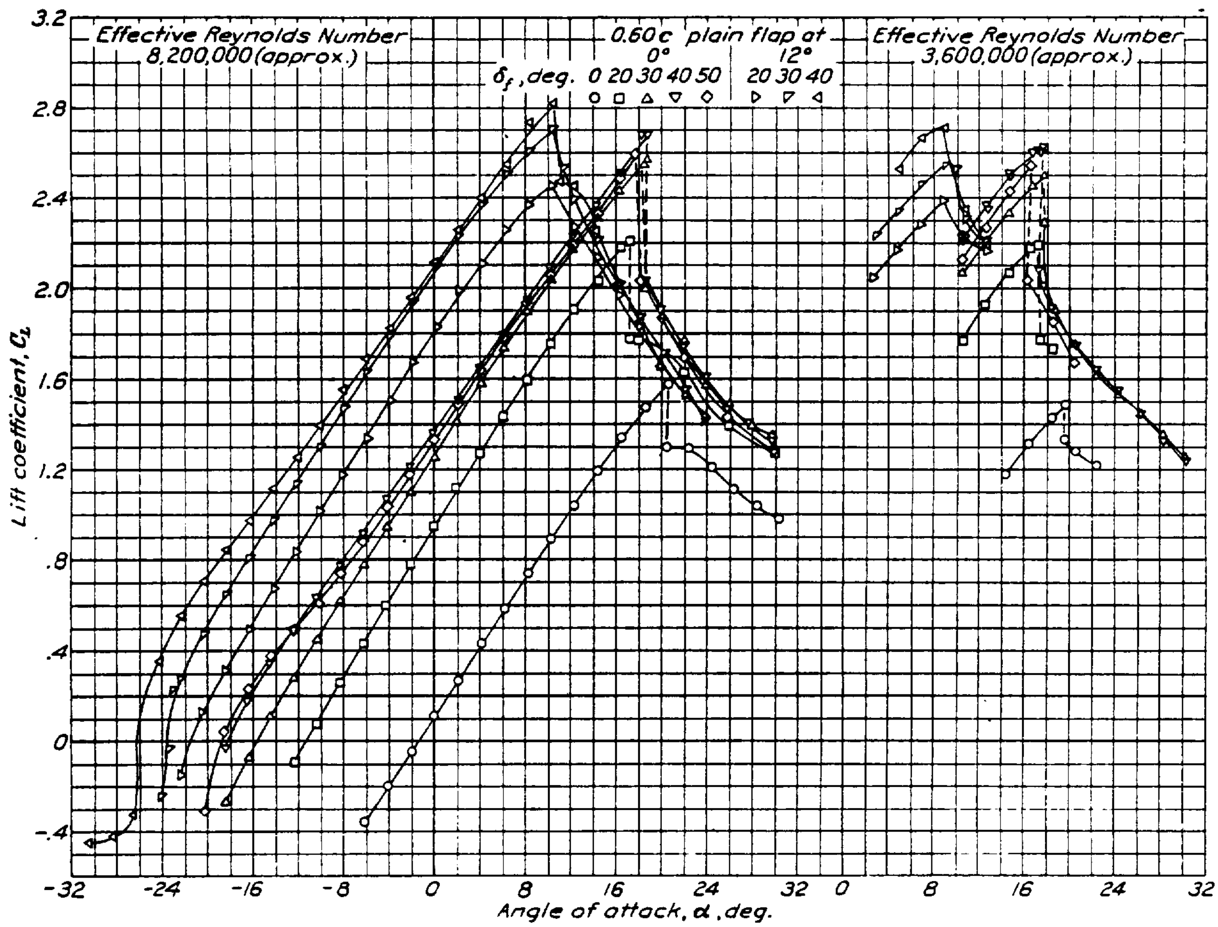


FIGURE 34.—Lift against angle of attack for N. A. C. A. 23012 airfoil with 0.2566c slotted flap 2-h, rectangular wing, aspect ratio 6.

PROFILE DRAG

The wing with the slotted flap in the neutral position had 15 percent higher minimum drag than the plain airfoil, as shown in figure 38. In order to find out to what extent this drag increment could be reduced by preventing flow through the slot, tests were made with the upper slot closed. The closing of the slot exit had practically no effect on the drag. If the slot is perfectly sealed when the flap is neutral, a decrease of the minimum drag of the order of 15 percent may accordingly be expected.

The drag of the wing at high lifts, with slotted flap 2-h deflected to its most favorable position at each lift coefficient, is included in figure 39. This curve, which may be called a profile-drag envelope polar, is the envelope of all the polars for the wing with all flap settings. A series of such curves for various flap types and arrangements shows the relative merit of each type for such an item of performance as take-off where, other things being equal, lower drag at high lift coefficients is advantageous. Such a series of curves (fig. 39) shows the 0.2566c slotted flap 2-h to be definitely superior to the 0.20c plain and split flaps, as was also shown by the 7- by 10-foot tunnel tests. Slotted flap 2-h is also slightly superior to the external-airfoil flap on the basis of low drag and is greatly superior to it on the basis of maximum lift. The data for these other flap arrangements are taken from references 2 and 19.

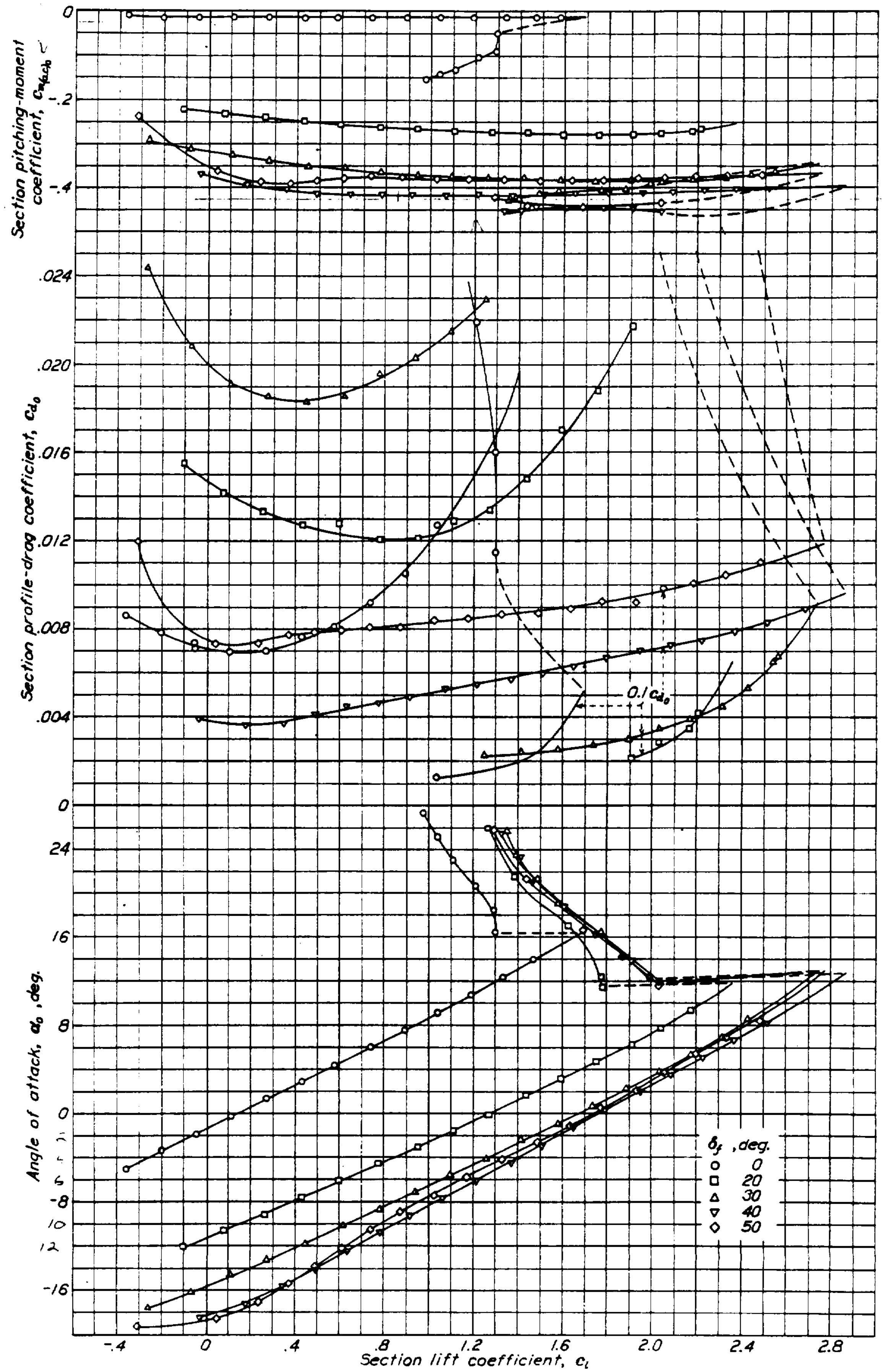


FIGURE 35.—Section aerodynamic characteristics of N. A. C. A. 23012 airfoil with 0.2566c slotted flap 2-h and the 0.60c plain flap neutral. Effective Reynolds Number, approximately 8,200,000.

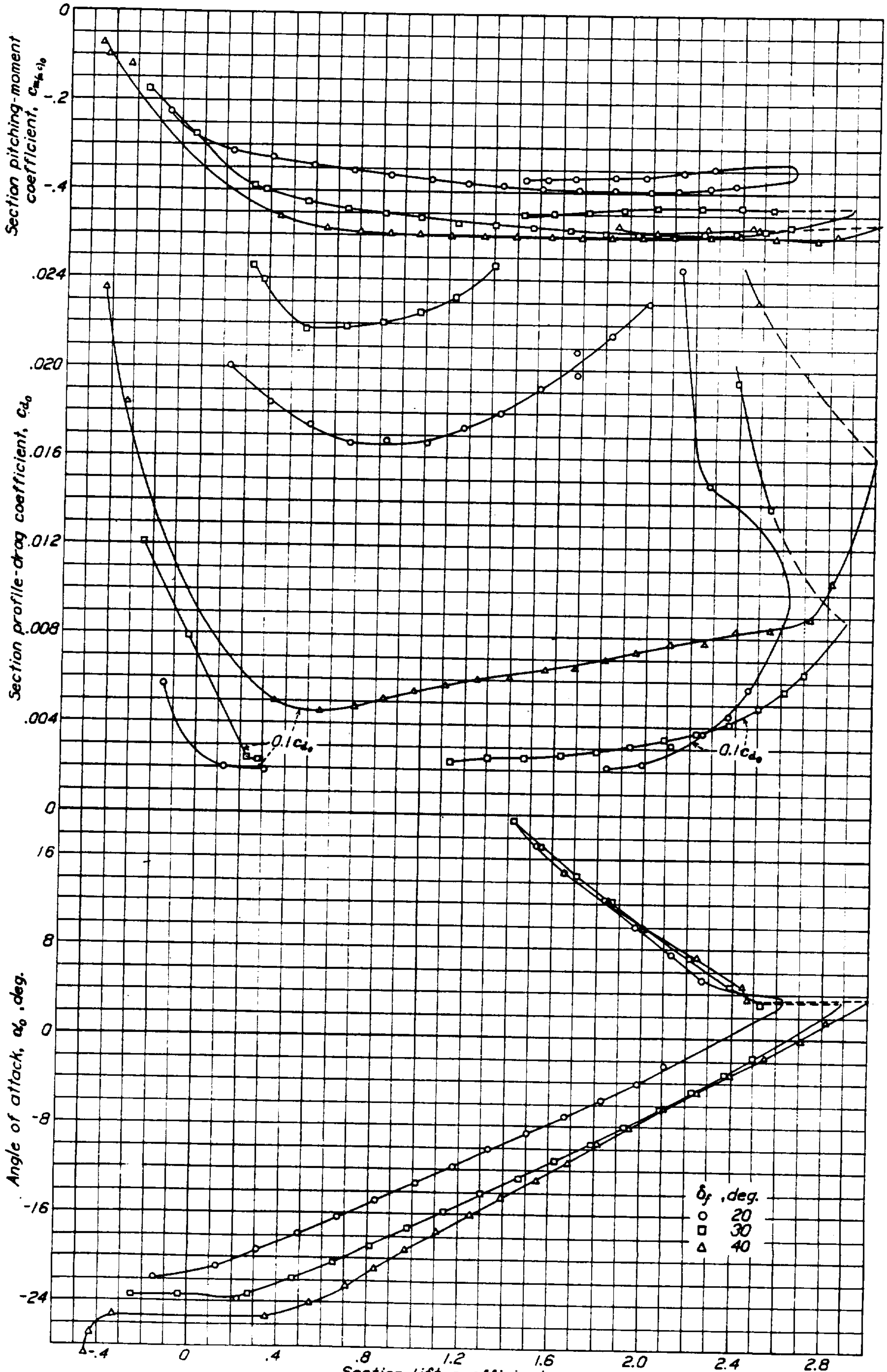


FIGURE 36.—Section aerodynamic characteristics of N. A. C. A. 23012 airfoil with 0.2566c slotted flap 2-h and the 0.60c plain flap deflected 12°. Effective Reynolds Number, approximately 8,200,000.

PITCHING-MOMENT COEFFICIENT

The pitching-moment coefficient increased with flap deflection up to 40°. The pitching moment for the same deflection is greater than that of the plain and the split flaps but, when the comparison is made on the basis of deflections giving the same lift at the same angle of attack, the pitching moments are the same for all three flaps.

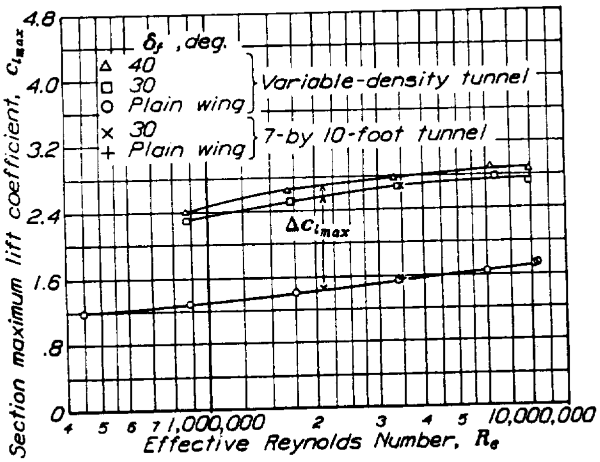


FIGURE 37.—Scale effect on $c_{l_{max}}$ for N. A. C. A. 23012 airfoil with and without 0.2566c slotted flap 2-h.

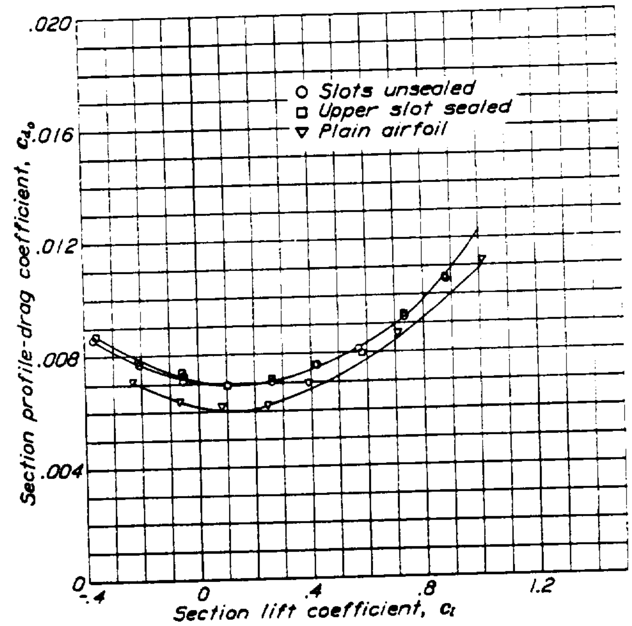


FIGURE 38.—Effect of slot opening on profile drag of N. A. C. A. 23012 airfoil with slotted flap 2-h neutral. Effective Reynolds Number, approximately 8,200,000.

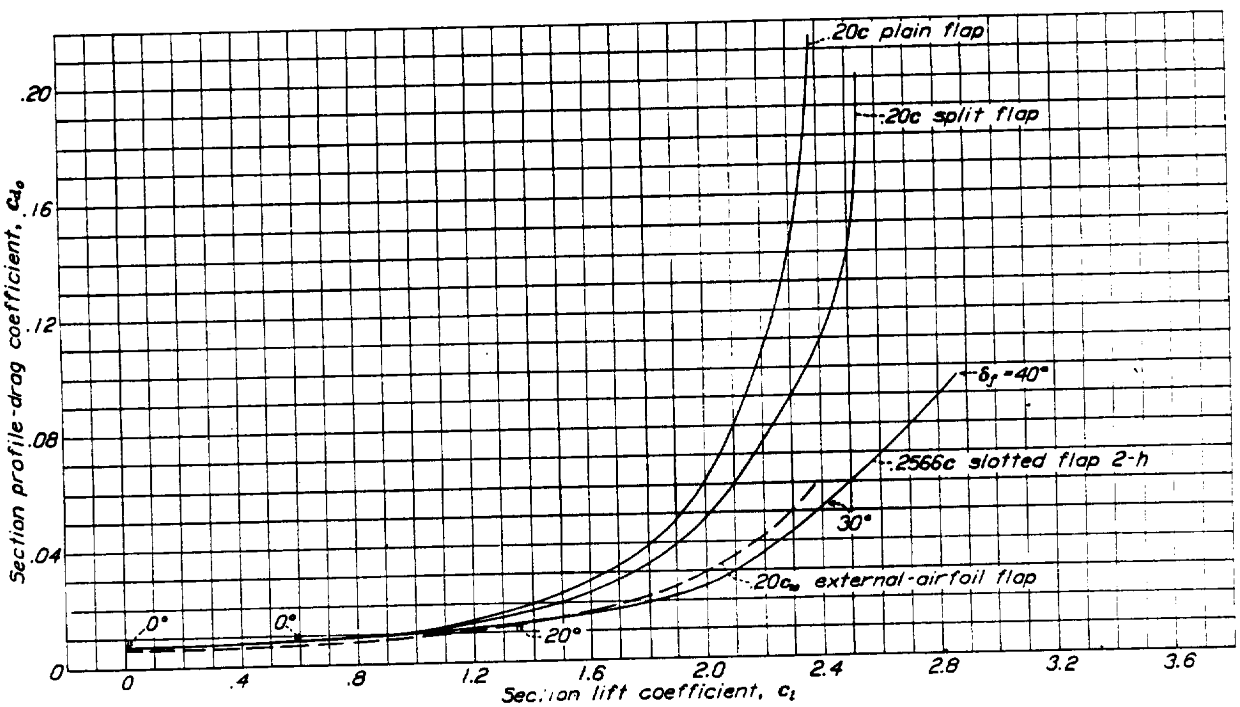


FIGURE 39.—Profile-drag envelope polars, N. A. C. A. 23012 airfoil with various flaps. Effective Reynolds Number, approximately 8,200,000.

CONCLUSIONS

1. The optimum arrangement of the slotted flap tested was superior to the split, the plain, and the external-airfoil types of flap compared on the basis of maximum lift coefficient, low drag at moderate and at high lift coefficients, and high drag at high lift coefficients. The slotted flap, however, gave slightly lower maximum lift coefficients than the Fowler flap.
2. The increment of maximum lift due to the slotted flap was found to be practically independent of the Reynolds Number over the range investigated.
3. Openings in the lower surface of the airfoil for the slotted flaps tested had a measurable effect on the drag for high-speed flight conditions even when the slot was smoothly faired to maintain the contour of the upper surface and there was no air flow through the slot.
4. The slotted flap gave the highest maximum lift coefficients when the nose of the flap was located slightly ahead of and below the slot lip and with a slot lip that directed the air down over the flap.
5. The lowest profile drags at moderate lift coefficients were obtained by using a slotted flap with an airfoil nose shape and with an easy entrance to the slot.
6. It appears that still further improvement may be obtained in low drag characteristics at moderate and high lift coefficients by the use of multiple flaps or by slotted flaps with greater lip extensions.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., *February 12, 1938.*

TABLE I

ORDINATES FOR AIRFOIL AND SLOT SHAPES

[Stations and ordinates in percent of wing chord]

N. A. C. A. 23012 Airfoil		
Station	Upper surface	Lower surface
0	------------	0
1.25	2.67	−1.23
2.5	3.61	−1.71
5	4.91	−2.26
7.5	5.80	−2.61
10	6.43	−2.92
15	7.19	−3.50
20	7.50	−3.97
25	7.60	−4.28
30	7.55	−4.46
[illegible]	7.14	−4.48
50	6.41	−4.17
60	5.47	−3.67
70	4.36	−3.00
80	3.08	−2.16
90	1.68	−1.23
95	.92	−.70
100	.13	−.13
L. E. radius: 1.58. Slope of radius through end of chord: 0.305.		

TABLE I—Continued

ORDINATES FOR AIRFOIL AND SLOT SHAPES—Con.

Slot shape e	
Station	Ordinate
74.89	−0.18
75.41	.59
75.93	1.18
76.46	1.64
77.50	2.32
78.98	2.87
80.00	2.97

Slot shape f	
Station	Ordinate
74.89	−0.18
75.41	.59
75.93	1.18
76.46	1.64
77.50	2.32
78.98	2.87
80.00	2.97
81.70	2.72

Slot shape i	
Station	Ordinate
74.42	------------
74.74	−0.22
75.06	.13
75.69	.68
76.33	1.11
76.97	1.46
78.25	2.00
79.53	2.36
80.81	2.59
82.08	2.68
82.50	2.60

TABLE II

ORDINATES FOR FLAP SHAPES

[Stations and ordinates in percent of wing chord]

Flap 1		
Station	Upper surface	Lower surface
0	−1.61	−1.61
.52	−.18	------
1.04	.58	−2.41
1.56	1.16	−2.43
2.09	1.63	−2.42
3.13	2.30	−2.37
4.61	2.84	------
5.63	2.97	−2.16
6.82	2.88	------
15.63	1.68	−1.23
20.63	.92	−.70
25.63	.13	−.13
Center of L. E. arc		
0.72	−1.61	
L. E. radius: 0.72		

TABLES II—Continued

ORDINATES FOR FLAP SHAPES—Continued

Flap 2		
Station	Upper surface	Lower surface
0	−1.29	−1.29
.40	−.32	−2.05
.72	.04	−2.21
1.36	.61	−2.36
2.00	1.04	−2.41
2.64	1.40	−2.41
3.92	1.94	------
5.20	2.30	------
5.66	------	−2.16
6.48	2.53	------
7.76	2.63	------
9.03	2.58	------
10.31	2.46	------
15.66	1.68	−1.23
20.66	.92	−.70
25.66	.13	−.13
Center of L. E. arc		
0.91	−1.29	
L. E. radius: 0.91		

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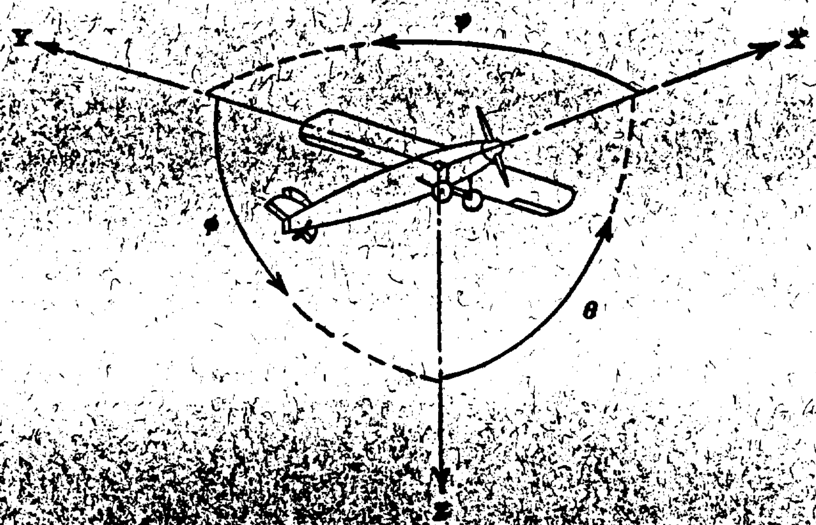

Positive directions of axes and angles (forces and moments) are shown by arrows

Axis		Force (parallel to axis) symbol	Moment about axis			Angle		Velocities	
Designation	Symbol		Designation	Symbol	Positive direction	Designation	Symbol	Linear (component along axis)	Angular
Longitudinal	X	X	Rolling	L	Y→Z	Roll	φ	u	p
Lateral	Y	Y	Pitching	M	Z→X	Pitch	θ	v	q
Normal	Z	Z	Yawing	N	X→Y	Yaw	ψ	w	r

Absolute coefficients of moment

$C_l=\frac{L}{qbS}$ (rolling) $C_m=\frac{M}{qcS}$ (pitching) $C_n=\frac{N}{qbS}$ (yawing)

Angle of set of control surface (relative to neutral position), δ. (Indicate surface by proper subscript.)

4. PROPELLER SYMBOLS

D, Diameter
p, Geometric pitch
p/D, Pitch ratio
V', Inflow velocity
V_s, Slipstream velocity
T, Thrust, absolute coefficient $C_T=\frac{T}{\rho n^2 D^4}$
Q, Torque, absolute coefficient $C_Q=\frac{Q}{\rho n^2 D^5}$
P, Power, absolute coefficient $C_P=\frac{P}{\rho n^3 D^5}$
C_s, Speed-power coefficient $=\sqrt[5]{\frac{\rho V^5}{P n^2}}$
η, Efficiency
n, Revolutions per second, r.p.s.
Φ, Effective helix angle $=\tan^{-1}\left(\frac{V}{2\pi r n}\right)$

5. NUMERICAL RELATIONS

1 hp.=76.04 kg-m/s=550 ft-lb./sec.
1 metric horsepower=1.0132 hp.
1 m.p.h.=0.4470 m.p.s.
1 m.p.s.=2.2369 m.p.h.
1 lb.=0.4536 kg.
1 kg=2.2046 lb.
1 mi.=1,609.35 m=5,280 ft.
1 m=3.2808 ft.

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